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INDIANA

DEPARTMENT OF HIGHWAYS

JOINT HIGHWAY RESEARCH PROJECT

JHRP-85/5

DEVELOPMENT OF AN ENERGY AUDIT
MANUAL FOR INDIANA DEPARTMENT
OF HIGHWAYS BUILDINGS

FINAL REPORT

Brett Michael Partridge



PURDUE UNIVERSITY



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by

Brett Michael Partridge
Graduate Instructor in Research

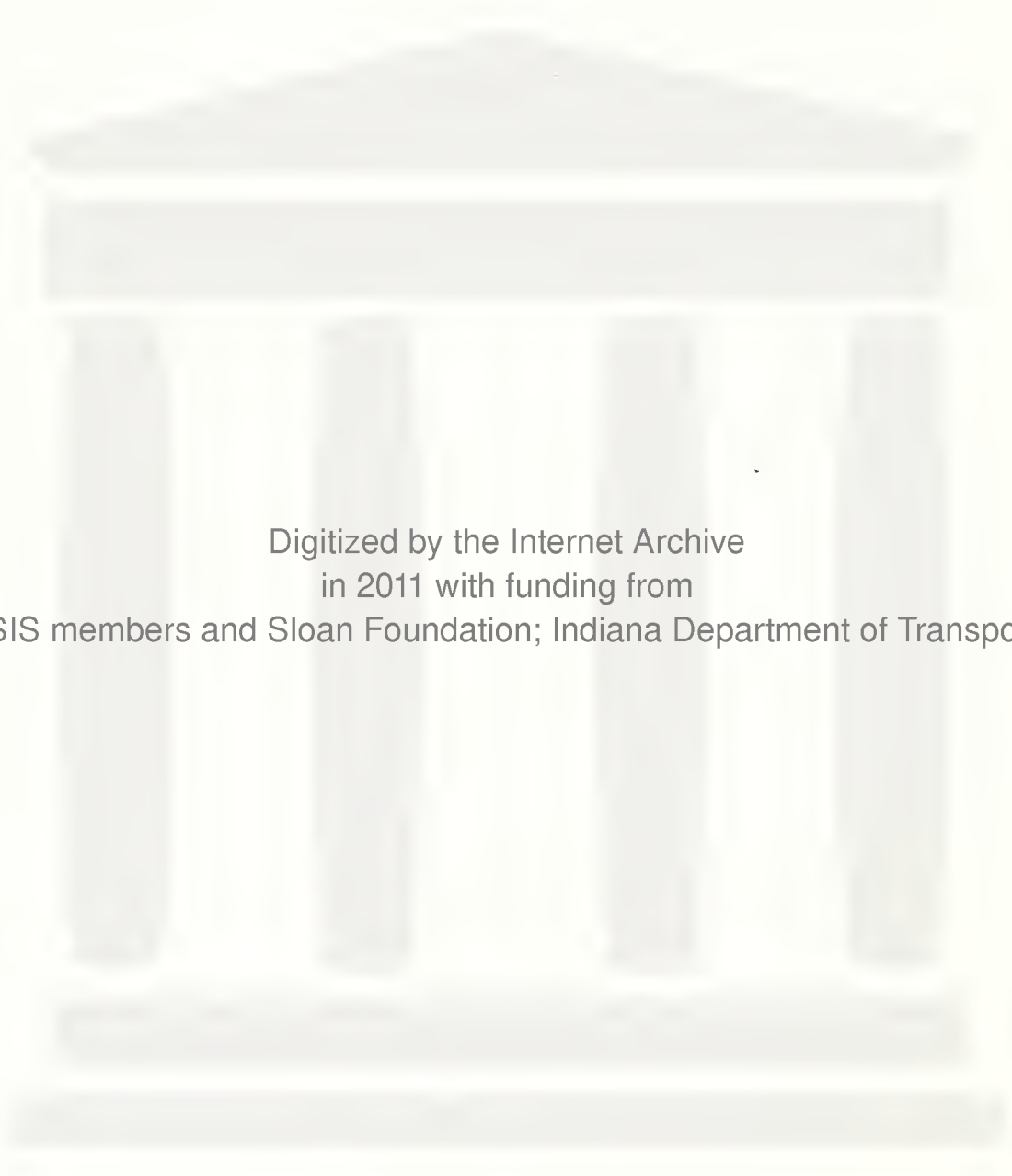
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ABSTRACT

Partridge, Brett Michael. MSCE, Purdue University, May 1985, Development of An Energy Audit Manual For Indiana Department of Highway Buildings. Major Professor: Donn E. Hancher.

The purpose of this study was to develop an Energy Audit Manual for the Indiana Department of Highways for use in completing in-house audits of their existing buildings. The major objective in writing the manual was to provide a series of step by step procedures that would allow an individual to effectively audit an IDOH facility. The manual is divided into seven chapters with each one covering a major step in completing an energy audit.

The manual instructs the user through a data gathering process. This data is then used to determine how the building is using its energy supply. Based on this information, alternative energy conservation opportunities are economically evaluated to determine which energy conservation opportunities can be cost effectively implemented. A simple payback period of four to five years is used to determine if the energy conservation opportunities are cost effective.

CHAPTER 1 INTRODUCTION

1.1 Statement of Purpose

An energy audit is the evaluation of energy consumption within a facility to enable the determination of energy conservation opportunities within that facility. The goal in energy conservation is to reduce the amount of energy required to operate a facility and still maintain an acceptable working environment. A reduction in the energy use for a facility will decrease the dollar amount that must be spent on its utility bills.

The purpose of this study was to develop an Energy Audit Manual for the Indiana Department of Highways. The purpose of the manual is to enable the IDOH to perform energy audits on their maintenance and office buildings. The majority of these buildings were constructed prior to the energy crunch of the early seventies. Prior to this time, buildings were constructed without any regard to the energy efficiency of the facility; therefore, several energy conservation opportunities exist within this group of buildings.

1.2 Objectives

The primary objective of this study was to develop an Energy Audit Manual that will enable the Indiana Department of Highways to continue their energy conservation program. In developing the manual four key objectives were set. The first objective was to write the manual so that a person without a lot of experience in the energy auditing process can effectively audit a building by using this manual. The first-time user of this manual should read through the whole manual and then study those sections of the manual in more detail that seem unclear.

The second objective was to cover the major energy conservation opportunities that exist within existing buildings. To do this the manual will focus on the physical components and lighting systems of a building. The physical components include the floors, walls, roof, windows and doors. The lighting system includes all interior lighting and exterior lighting. These two areas of a building can often have changes made in either the physical characteristics or maintenance procedures to increase the energy consumption efficiency of the building. Other areas of energy conservation such as electrical building loads and mechanical equipment will not be covered in this manual. Analysis of these systems requires an expertise that goes beyond the scope of this manual. However, this is an important area in

energy conservation and analysis of these systems will provide cost effective energy conservation opportunities. The goal of this manual is to cover the major energy conservation opportunities that exist within the building structure and lighting systems which can be identified by Department of Highway's personnel using this manual.

The third objective was to identify specific areas within a building where possible energy conservation opportunities exist. Once these areas are identified, alternative solutions can then be evaluated to determine which ones are the most cost effective. These alternative solutions will be evaluated on the basis of a minimum four to five year payback period.

The fourth objective was to present an evaluation procedure to determine which energy conservation opportunities are the most economical, and are within the prescribed payback periods. This will enable the energy auditor to determine which energy conservation opportunities will return the optimal energy dollar savings per dollar spent on implementing the energy conservation opportunities within the prescribed payback period.

1.3 Energy Audit Process

This manual proposes seven major steps in the energy audit process. Each major step is covered in a separate

chapter. Chapter 1 is the introduction to this manual. Chapters 2 through 8 cover the seven major steps of the energy audit process.

Chapter 2, Building Selection, presents a selection procedure to aid in selecting a building out of the possible candidates for an energy audit. Chapter 3, Building Information Form, is probably the most important chapter of the manual. The Building Information Form, referred to as BIF, is a data gathering form used to collect the necessary data for completing an energy audit. If the BIF is properly filled out, experts in the energy audit field can be consulted if the need arises and the information regarding the particular problem can be effectively communicated to them. Chapter 4, Building Site Visit, explains the steps to take when the energy auditor walks through the building, and what to be looking for in terms of energy conservation. Chapter 5, Heat Loss Calculations, explains how to use the information on the BIF for determining a building's heat loss during the winter months. Chapter 6, Lighting Calculations, explains how to use the information on the BIF for analyzing the lighting systems. Chapter 7, Energy Consumption Survey, explains how to determine a comparable energy consumption using a standard measure for each building from the utility bills. Chapter 8, Energy Conservation Opportunity Analysis, outlines the procedures for determining what energy conservation opportunities have a cost effective return.

The flow of the energy audit process is shown in Figure 1.1. Due to the age of some buildings and the fact that the State purchased some buildings from previous owners, blueprints are not available for all IDOH buildings. Therefore, depending upon whether or not a set of blueprints are available will determine in which order the BIF and Site Visit is completed.

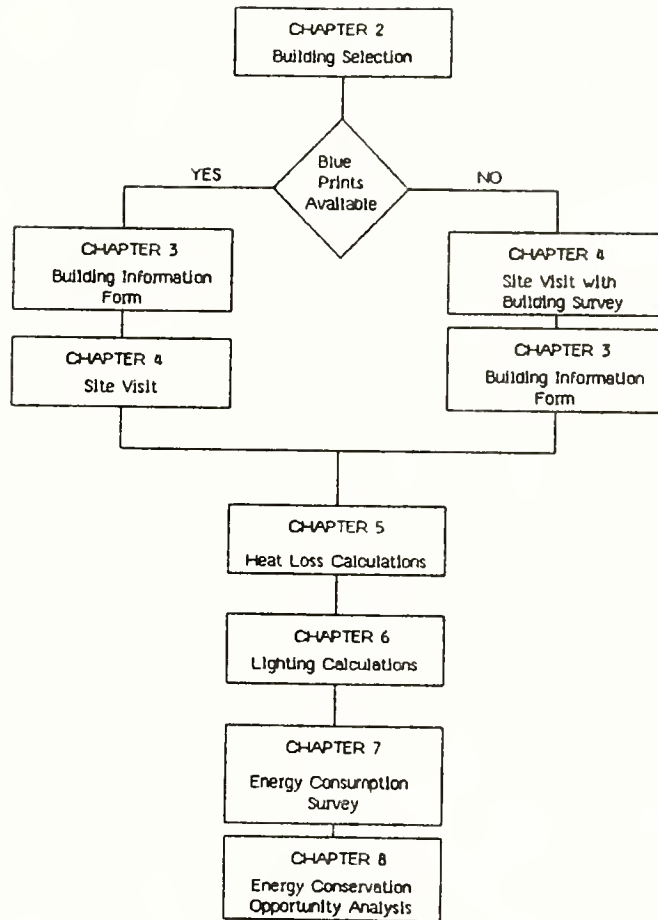


Figure 1.1 Energy Audit Flow Diagram

CHAPTER 2 BUILDING SELECTION

2.1 Introduction

The Indiana Department of Highways is responsible for the operation and maintenance of several hundred buildings. The energy efficiency of these buildings ranges from good to poor. Newer buildings constructed after the 1973 energy crisis are more energy efficient than buildings constructed prior to this time. Therefore, it makes sense to audit the older buildings, or least energy efficient buildings, first. To determine which buildings to audit first would require an in-depth study and would not be worth the expense. Using a few key variables that affect a building's utility bills, however, a quick estimate of which buildings to audit first can be made. Based on the age of the building, the number of hours per week that the building is in operation, and the dollars per square foot spent on the building's utility bills, a quick estimate of which buildings to audit first can be made.

2.2 Procedures for Selecting a Building

To make the building selection process manageable, it is suggested that it be done on a district by district basis. Within each district a person would be assigned the task of gathering the necessary data to select which buildings to audit first. Analyzing the buildings by districts will divide the several hundred buildings within the State into six manageable groups.

A previous study entitled "An Investigation of Potential Energy Conservation Opportunities for Indiana Department of Highway Buildings" by G. Smith [1] classified the buildings within the State into six major building types and buildings that did not resemble a particular type were classified as "other". Figure 2.3, located at the end of this chapter, shows the six major building types and gives brief descriptions of each type.

The selection process presented below is based on three assumptions that should be understood prior to, and when using this selection procedure. The first assumption is that all buildings that have been previously audited are excluded from the selection process.

Second, buildings that are of similar construction and operate under the same conditions should consume the same relative amount of energy. Operating conditions that effect

a building's energy consumption include many factors. Some of the major ones are the weather, peoples' habits who use the building, and the building's energized systems. Energized systems include lighting, HVAC equipment and any other system that requires energy to operate. Two buildings of similar construction will have different energy consumption patterns if the operating conditions are different. For example, a building that is in the northern section of the State will consume more energy during the winter than a building in the southern section of the State due to the difference in weather. However, the weather conditions within each district is relatively the same. By evaluating the buildings against each other according to district, the majority of the weather bias will be eliminated. Another example would be a building that required large electrical loads to run a heavy piece of equipment, this would consume more energy than a similar building without the operation. Therefore, if a building has an operation unique to the group, it should not be grouped and ranked with the other buildings.

Third, buildings that have been put into the "Other" classification can not be ranked against each other using the procedure presented below. These buildings along with the unique buildings within their type will have to be evaluated on a building by building basis.

Within each district, the following procedures would be followed to rank and select which buildings to audit first.

STEP 1: Group the buildings into type I through VI and Other as shown in Figure 2.3.

STEP 2: Determine the following items for each building.

- * year of construction

- * hours per week the building is operated

- * gross conditioned floor area in square feet

- * utility expense for the previous 12 months

STEP 3: Enter the information from step 2 onto Form 2.1, Building Selection, see Figure 2.1, as follows:

Column 1 - Enter a descriptive name for each building and group according to type

Column 2 - Year of construction

Column 3 - Rank each building according to "Year of construction," oldest year, No. 1, etc...

Column 4 - Enter the hours per week the building is occupied

- Column 5 - Rank the buildings according to "hours used," most hours, No.1, etc...
- Column 6 - Enter the area in square feet of conditioned floor space
- Column 7 - Enter the total utility expenses for the preceding twelve month period.
- Column 8 - Divide the utility expenses (Col. 7) by area (Col. 6)
- Column 9 - Rank the buildings by unit cost of utilities (Col. 8), with the highest cost equal to 1, etc...
- Column 10 - Total the numbers in columns 3,5 and 9.
- Column 11 - Rank the buildings according to the total in column 10 with the lowest total No.1, etc...

The buildings should be audited according to their ranking in column 11, with the lowest number audited first and so on. One may audit each building within each group first, before going to the next group; or, the worst buildings within each group could be audited first.

This selection process is offered only as a suggestion to help in determining which buildings to audit first. This method will not guarantee that the buildings audited first will have the greatest amount of energy conservation opportunities. To determine which building to audit first from the "other" group should be based on the building's importance to the operation of the State Highway Department. A copy of Form 2.1 can be found in Appendix A.

[illegible]

Figure 2.1 Form 2.1 Building Selection

2.3 Building Selection Example

The following example is presented to illustrate the building selection procedure. The data used in the example is fictitious but would resemble the data for a given district.

Figure 2.2 is Form 2.1 Building Selection filled in with the fictitious data. Entries for Building A from the type IV group are explained below.

Column 1-	Building A	
Column 2-	1935	Year of construction
Column 3-	1	Of the type I building A is the oldest
Column 4-	40	Building A is occupied 40 hours a week
Column 5-	2	Building A is occupied the second highest time (NOTE A,B,C all 2's)
Column 6-	600	Building A has 600 sq ft of conditioned space
Column 7-	2100	Building A had 2100 dollars in utility bills over the last twelve months
Column 8-	3.5	$2100/600 = 3.5$
Column 9-	2	3.5 is the second highest No. in column 8
Column 10-	5	Columns 3,5 and 9 sum to 5 for building A
Column 11-	1	Building A has the lowest Total in column 10 for buildings A to E of type I

Looking at the results of the type IV buildings, building A should probably be audited first, buildings C and D second, building B third and building E fourth.

If we look at types I to IV collectively, building A from type I, building C from type II, building A from type III, and building A from type IV should be the first buildings audited. The final order would depend on personal judgement, but it is suggested that one start with the older buildings.

Form 2.1 Building Selection						Auditor <u>Joe Smith</u>				
DISTRICT <u>Example</u>						Date _____				
1	2	3	4	5	6	7	8	9	10	11
Type Building	Year		Usage		Area	Utility \$	\$/SF		Tot	Rank
Type I										
Building A	1980	1	40	1	2852	3740	1.30	2	4	1
Building B	1981	2	40	1	2852	3000	1.00	3	6	3
Building C	1982	3	40	1	2852	4000	1.40	1	5	2
Type II										
Building A	1970	3	40	2	1900	1870	1.00	4	9	3
Building B	1965	2	40	2	2000	2200	1.10	2	6	2
Building C	1960	1	50	1	2500	3000	1.20	1	3	1
Building D	1971	4	40	2	1900	1700	.90	5	11	4
Building E	1960	1	40	2	1500	1600	1.07	3	6	2
Type III										
Building A	1960	1	50	1	6420	6000	.90	3	5	1
Building B	1965	2	40	2	5000	5500	1.10	2	6	2
Building C	1970	3	40	2	4000	5000	1.25	1	6	2
Type IV										
Building A	1935	1	40	2	600	2100	3.5	2	5	1
Building B	1950	3	40	2	900	2700	3	3	8	3
Building C	1960	4	40	2	600	2400	4	1	7	2
Building D	1940	2	50	1	900	1800	2	4	7	2
Building E	1965	5	50	1	1000	1500	1.5	5	11	4

Figure 2.2 Form 2.1 Building Selection Example

Figure 2.3 Building Type Classification

Building Type I: New Block Design

General Description:

Frame - Block construction with a gabled roof.

Length: 62 feet

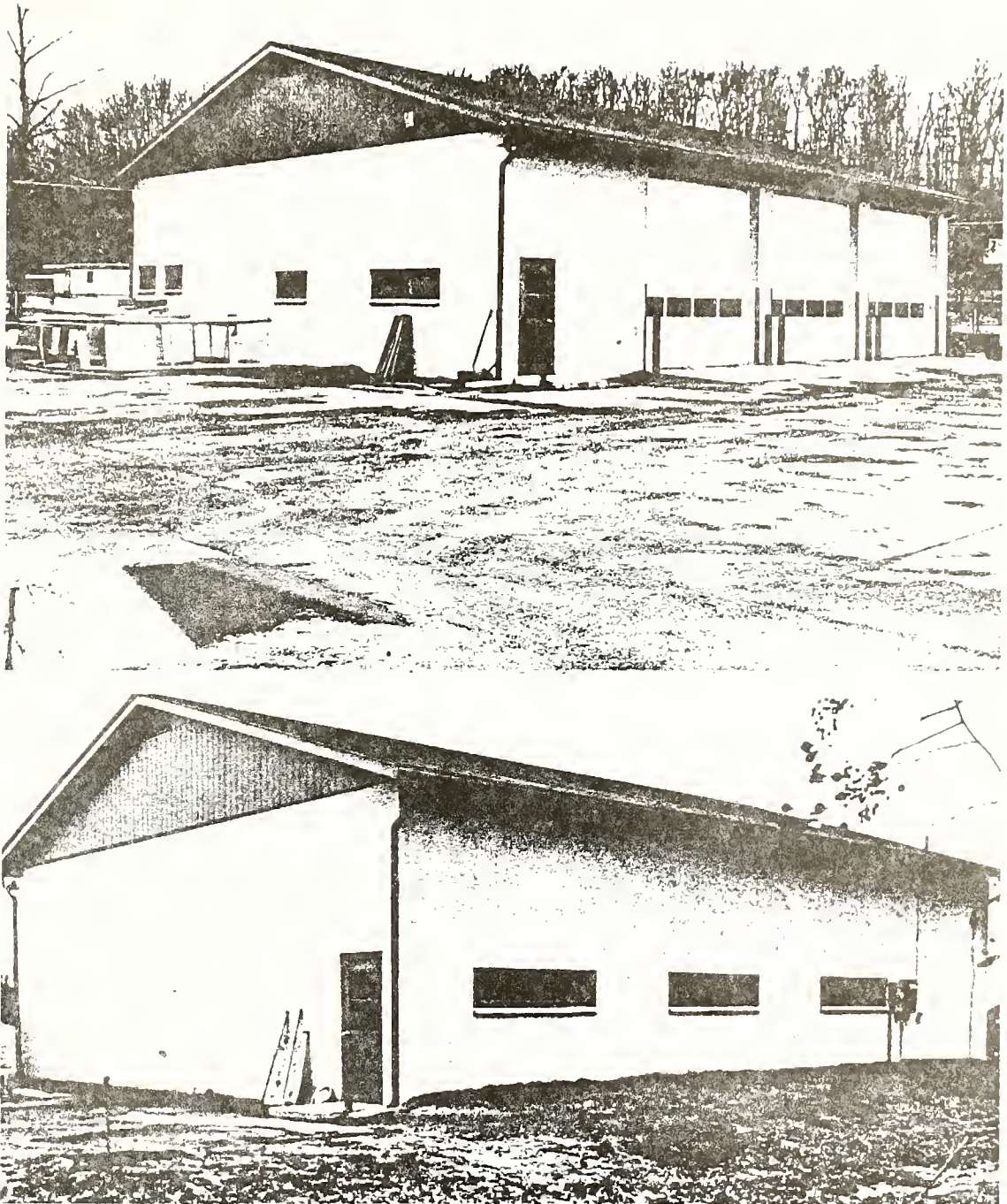
Width: 46 feet

Roof - Wood truss construction and an asphalt shingle roof.

Walls - 12" concrete blocks filled with granular insulation.

Use - Maintenance unit building.

Picture - One front view and one back view.



Building Type I

Figure 2.3 Building Type Classification

Figure 2.3 Continued

Building Type II: Small Metal Building

General Description:

Frame - Steel frame construction with a
gabled roof.

Length: 63.5 feet

Width: 30.0 feet

Roof - Galvanized metal roofing with two
inches of insulation.

Walls - Galvanized corrugated metal siding
with two inches of insulation.

Use - Unit storage building.

Picture - One front view.



Building Type II

Figure 2.3 Continued

Building Type III: Large Metal Building

General Description:

Frame - Steel frame construction with a
gabled roof.

Length: 160.5 feet

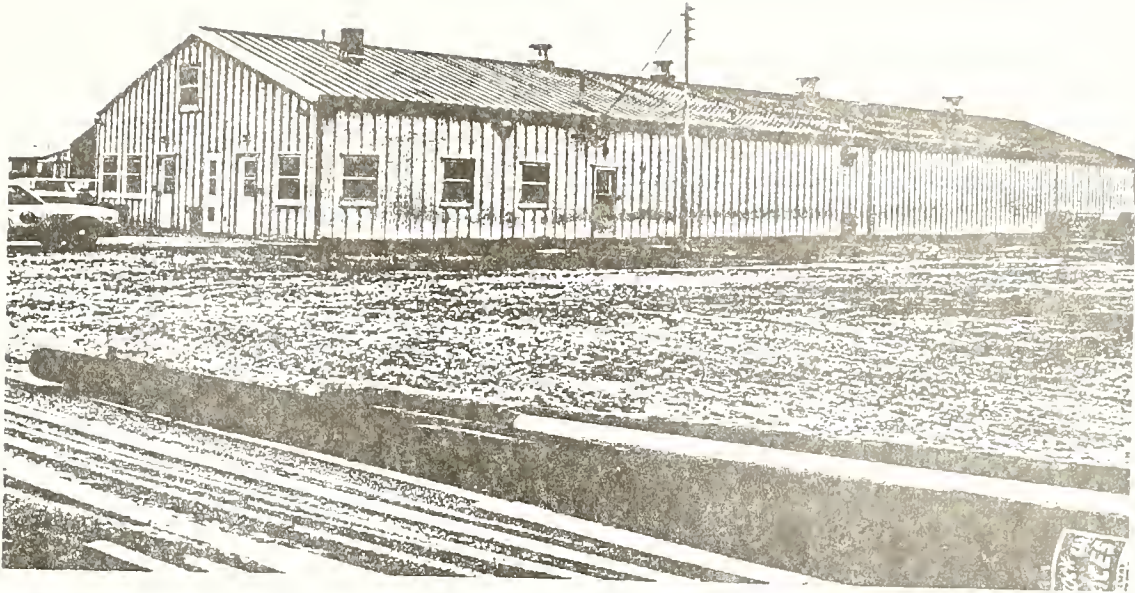
Width: 40.0 feet

Roof - Galvanized metal roofing with
two inches of insulation.

Walls - Galvanized metal siding with
three inches of insulation.

Use - Traffic operations building.

Picture - One front view and one back view.



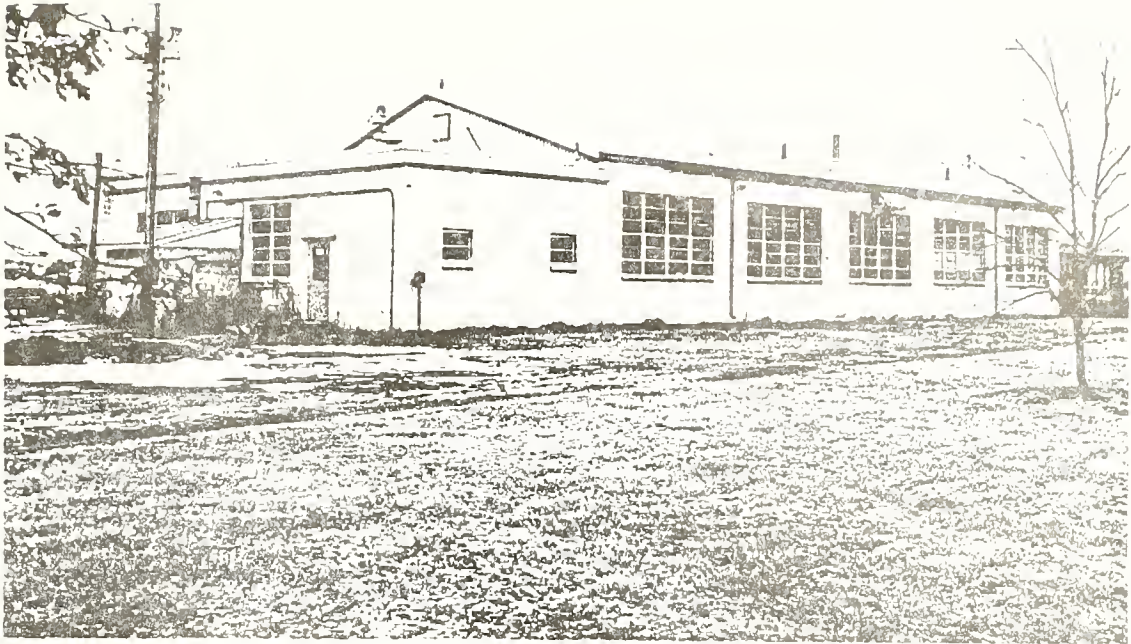
Building Type III

Figure 2.3 Continued

Building Type IV: Regular Block Design

General Description:

- Frame - Block wall construction
 Gabled roof for center section
 Flat roof for end sections.
- Length: 165.8 feet
 Width: 63.0 feet
- Roof - Center: Insulated metal panels.
 Outside: Concrete slab with a
 built-up roof.
- Wall - East section: 8" block and
 brick veneer.
 Center section: 12" block.
 West section: 12" block.
 Attic walls: Insulated metal
 siding.
- Use - Office and maintenance building.
- Picture - One front view and one rear view.



Building Type IV

Figure 2.3 Continued

Building Type V: Arched Roof Brick Design

General Description:

Frame - Masonry wall construction with
 an arch roof.

Length: 121.8 feet

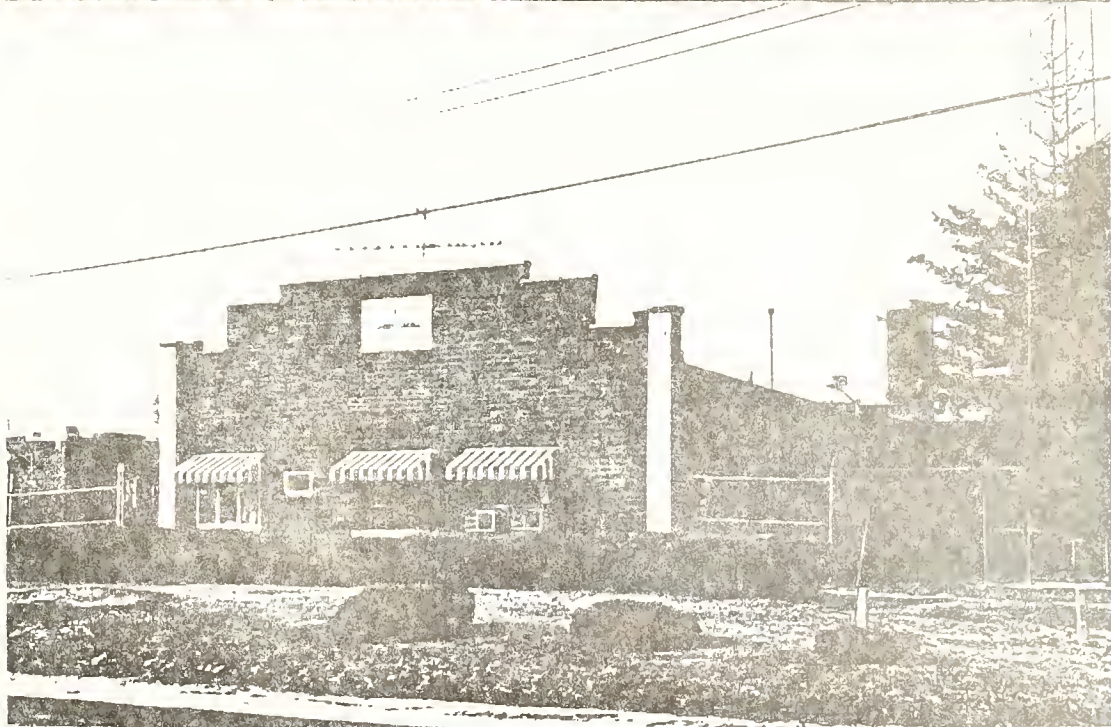
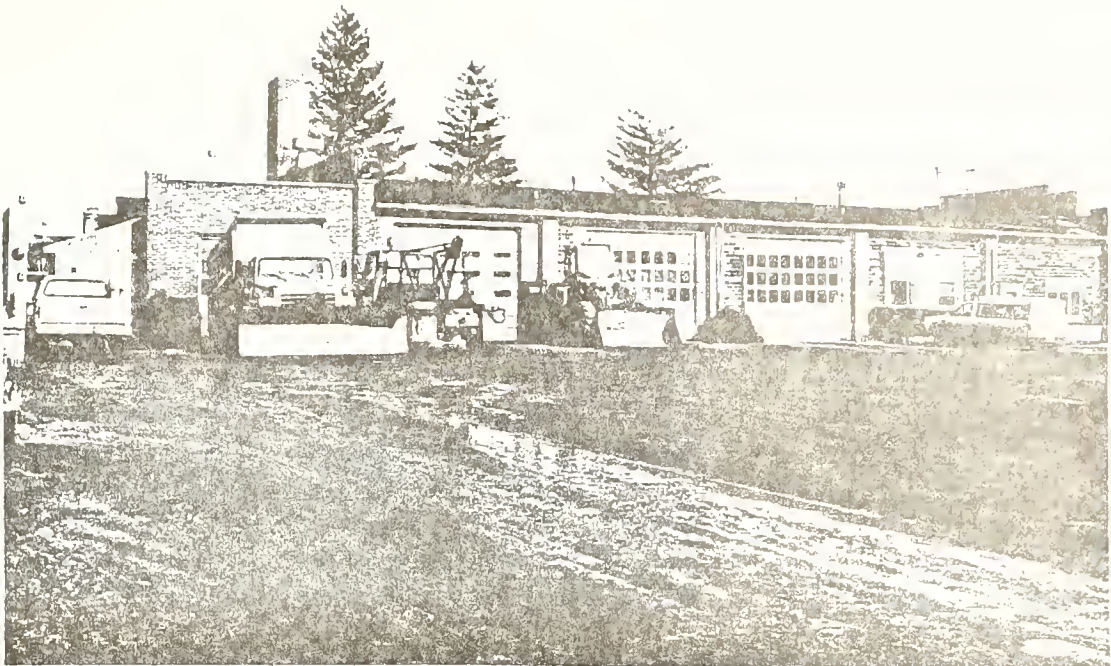
Width: 52.8 feet

Roof - Arched steel joist construction
 with a built-up roof.

Walls - Brick and concrete pilasters.

Use - Sub-district garage.

Picture - One front view and one side view.



Building Type V

Figure 2.3 Continued

Building Type VI: Shed Type Building

General Description:

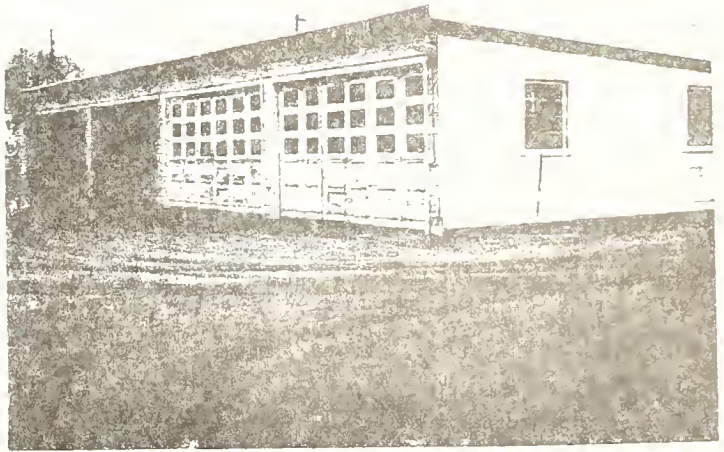
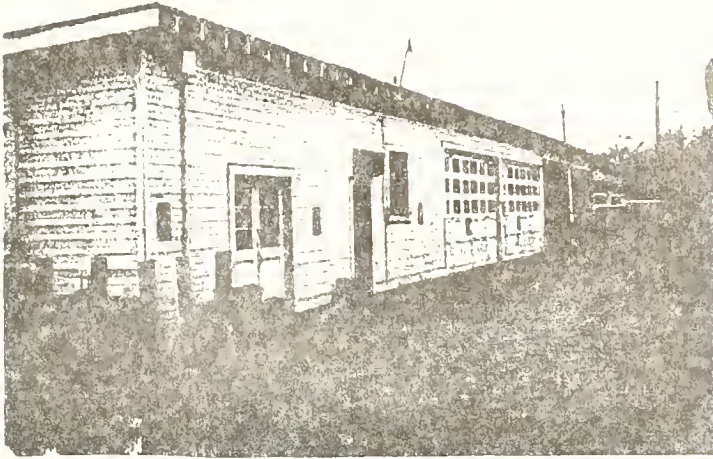
Frame - Wooden frame construction with
a flat pitched roof.

Roof - Roll roofing with wood truss
construction.

Wall - Paneling (outside walls
insulated).

Use - Supply building; storage.

Picture - Two front views and one back view..



Building Type VI

CHAPTER 3 BUILDING INFORMATION FORM

3.1 Introduction

After a building has been selected for an energy audit, the next step is to fill out the Building Information Form , referred to as a BIF. A complete set of BIF forms that are to be used in the energy audit process can be found in Appendix A. The BIF is a data gathering form used by the person doing the audit to collect the necessary physical and operational information about the facility to do an energy audit.

3.2 Required Material for Completing the BIF Form

To fill out the information required on the BIF the energy auditor will need to obtain a complete set of blueprints for the building being audited. If possible, this set of blueprints should be a set of as-built drawings. Also, try to obtain a set of specifications for the building. This will help in filling out the descriptive part of the BIF.

In most situations, only one set of BIF forms will be needed to audit a building. However, for buildings such as

the Type IV that have multiple sections, it is suggested that the energy auditor use as many BIF forms as there are sections. For example, the energy auditor would use three BIF forms for a Type IV building that had three distinct sections, see Figure 3.1 below.

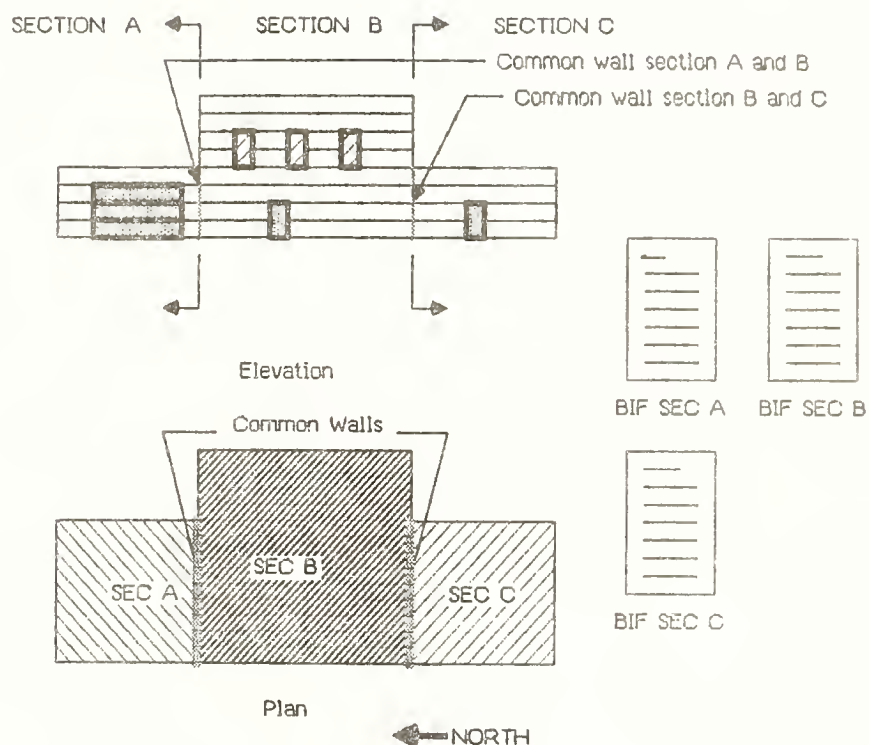


Figure 3.1 Building Type IV With Separate BIF Forms For Each Section

When auditing a building with multiple sections and using a separate BIF for each section, as shown in Figure 3.1, special attention will have to be paid to the common walls between the different sections. The common walls between section A and B and between sections B and C would

not be identified on the BIF if the inside temperature in sections A,B, and C were the same. When the temperature is the same in all sections, there is no heat loss between sections. If in Figure 3.1 each section had the same inside temperature, then the BIF for section A would have descriptions for the West, North, and EAST walls only. Section B would have descriptions for the West and East walls and for the portions of the North and South walls that were not common with section B and C. Section C would have descriptions for the East, South and West walls of section C.

When there is an inside temperature difference between two sections, heat losses between the two sections will have to be accounted for. For example, assume section A had an inside temperature of 60°F and section B had an inside temperature of 72°F . Therefore, there is a 12°F difference in temperature between the two sections and heat loss would be occurring from section B to section A at the common wall between sections A and B. Under this condition, the energy auditor would have to identify the common wall between sections A and B on the BIF and account for the heat loss in the heat loss calculations. This point will be discussed further in Chapter 5.

If a building that does not have a set of blueprints available is selected, the BIF will have to be filled out during the site visit. The specifics of filling out the BIF without a set of blueprints are covered in the next section.

3.3 Procedures for Completing the BIF Form.

The purpose of filling out the BIF is to collect data that will enable the energy auditor to do the heat loss and lighting calculations in Chapters 5 and 6, respectively. In order to do the heat loss calculations it is necessary to identify each exterior building component and interior component that separates conditioned and unconditioned space. A conditioned space is defined as one that has heat added via mechanical systems. An unconditioned space is one that does not have heat added. Figure 3.2 indicates the major building components and the conditioned and unconditioned space. Areas that heat loss will be taking place include the exterior walls, floors, roof, and walls and floors that surround the unconditioned space.

It is important to identify the building components by material and dimensions, and to identify the areas of different construction within the same component. For example, if the North wall in Figure 3.2 was constructed of block for the first 8 feet and wood for the remaining 9 feet. The section of the BIF for the North wall would have one description of the block construction, with its respective dimensions and a separate description for the wood construction with its dimensions listed. This point will be explained in more detail in section 3.4.

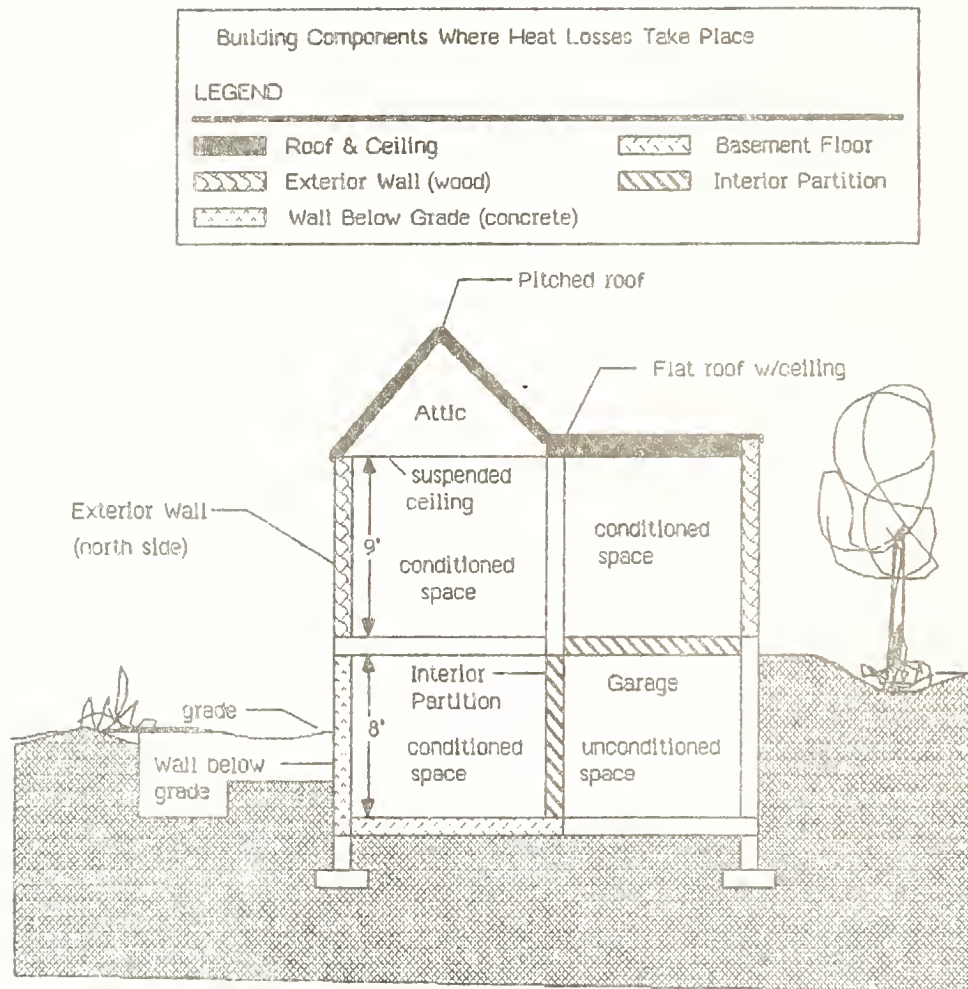


Figure 3.2 Location of Heat Losses Through Major Building Components

The general procedures to follow in filling out the BIF are explained below for a building that has a set of blueprints available. Next, the general procedures for filling out the BIF without a set of blueprints are explained. The specifics of filling out the BIF form along with an example are covered in section 3.4.

The general procedures for filling out the BIF with a set of blueprints are as follows:

1. Review the blueprints and identify the major building components.
2. Fill out the BIF as completely as possible. Some of the information requested on the BIF will have to be filled out during the site visit.
3. Complete site visit (see Chapter 4).
4. Complete BIF and go on to Chapter 5.

The general procedures for filling out the BIF without a set of blueprints are as follows:

1. Complete site visit and perform building survey (see Chapter 4).
2. Complete BIF and go on to Chapter 5.

3.4 Instructions for Filling Out the BIF Form with Examples

This section of Chapter 3 deals with the specifics of filling out the BIF form. Instructions are given for filling out the BIF and to help identify what type of information is required by the BIF. To help one understand the process of filling out the BIF and what type of information is required, an example building was created. This example building was then used to fill out an example BIF. The completed example BIF can be found at the end of this chapter.

Figures 3.3 to 3.14 on the following pages represent the example building used to fill out the example BIF. These figures represent the type of information that one would obtain from the blueprints or that one would have to determine from a building survey in order to fill out the BIF. Following Figure 3.14 are instructions for filling out the BIF form.

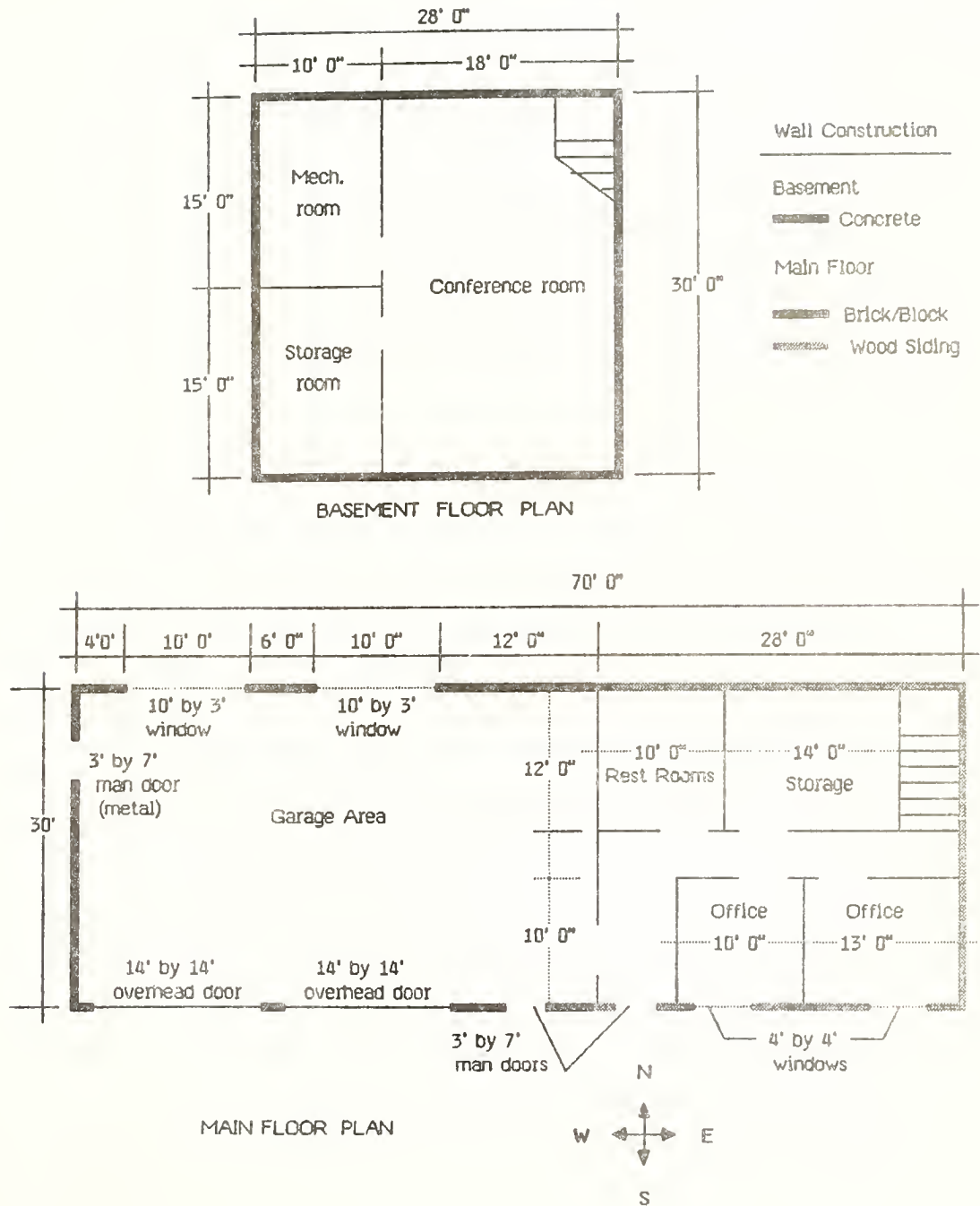


Figure 3.3 Example Building Floor Plans

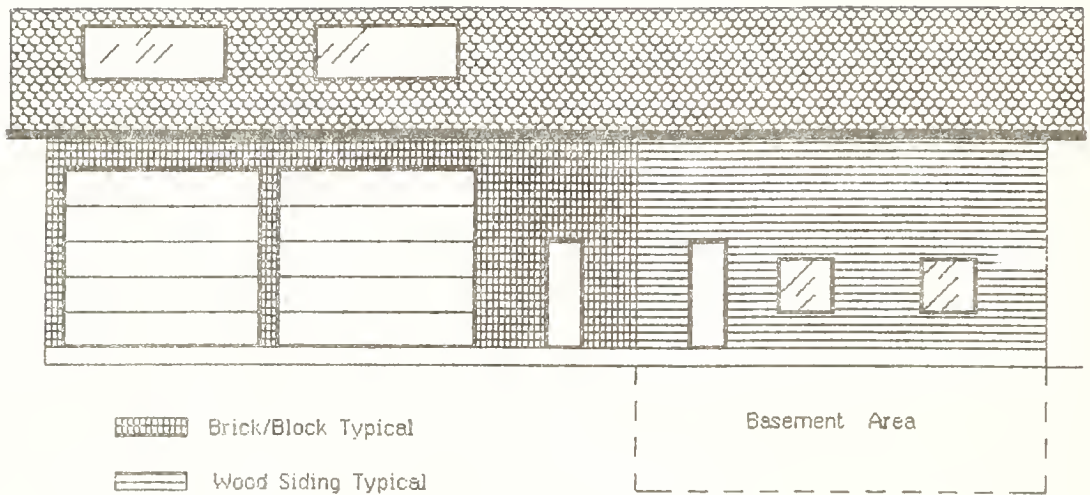


Figure 3.4 Example Building South Elevation

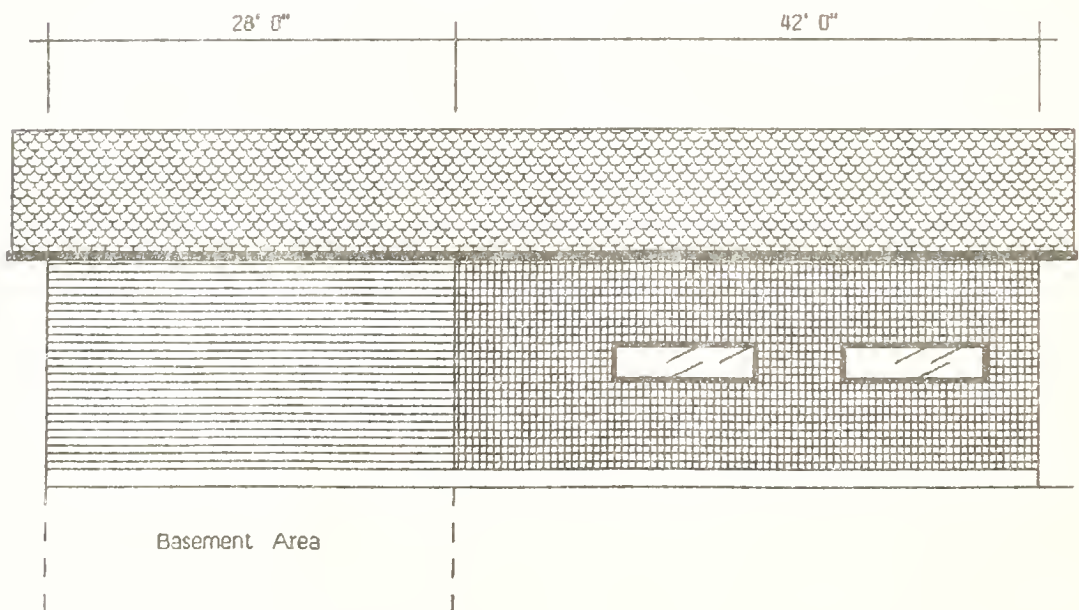


Figure 3.5 Example Building North Elevation

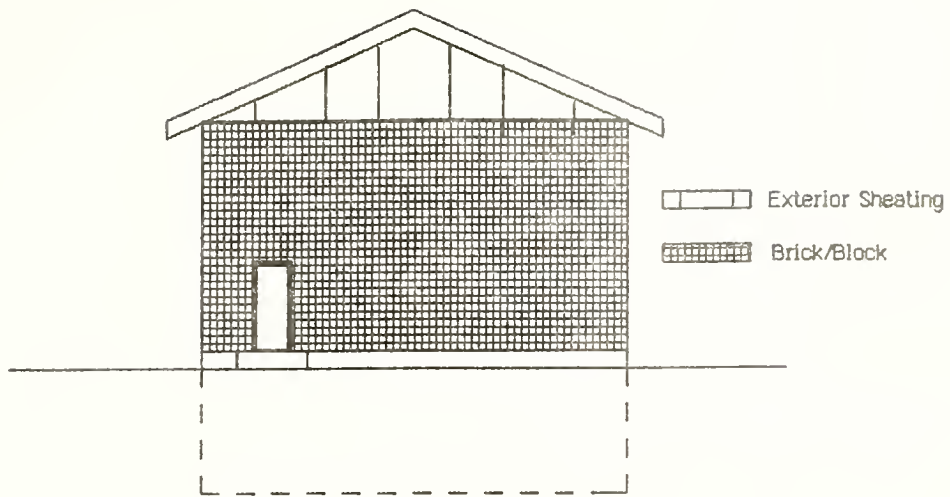


Figure 3.6 Example Building West Elevation

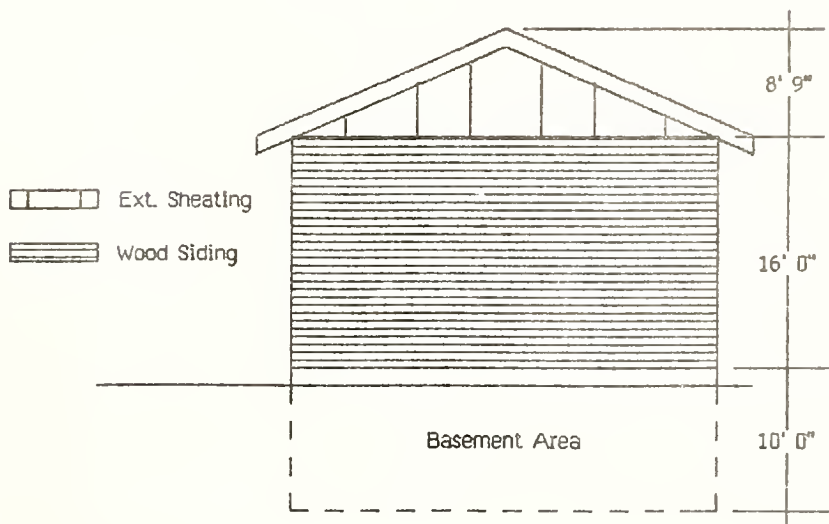


Figure 3.7 Example Building East Elevation

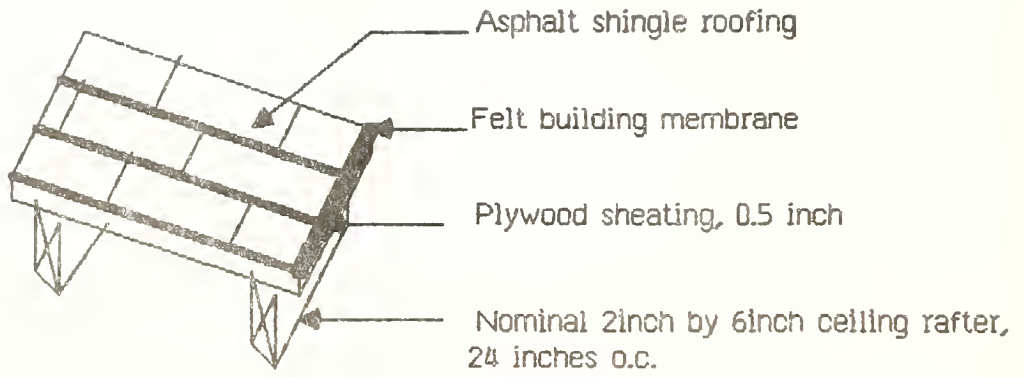


Figure 3.8 Typical Roof Section

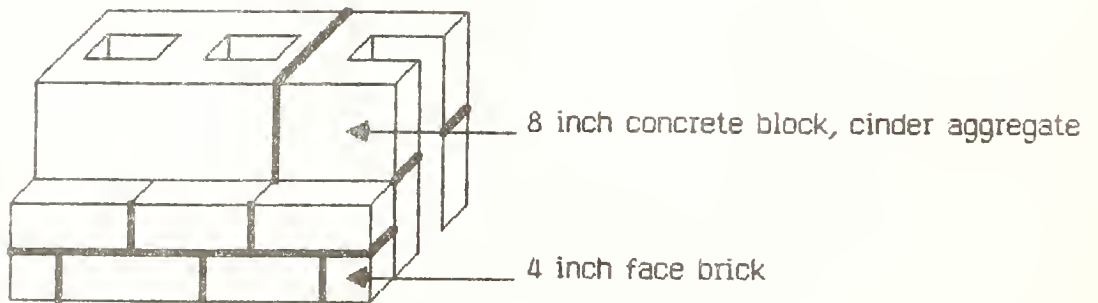


Figure 3.9 Typical Brick/Block Wall Section

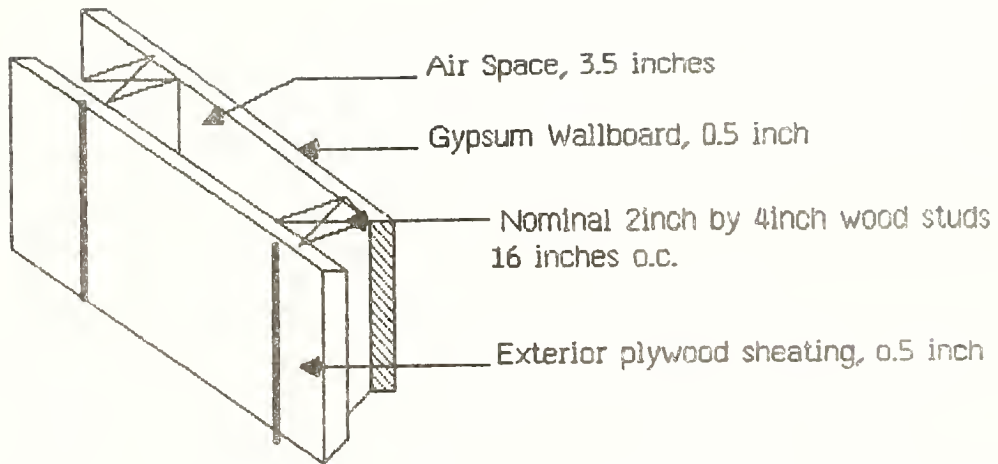


Figure 3.10 Typical Exterior Sheeting Section

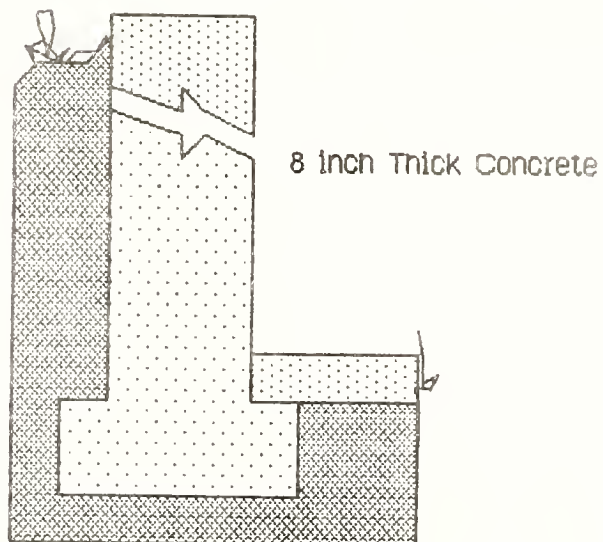


Figure 3.11 Typical Basement Wall Section

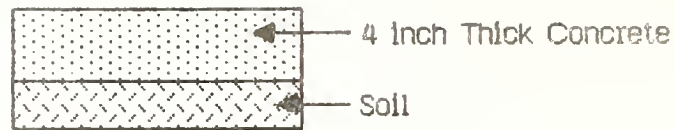


Figure 3.12 Typical Basement Floor Section

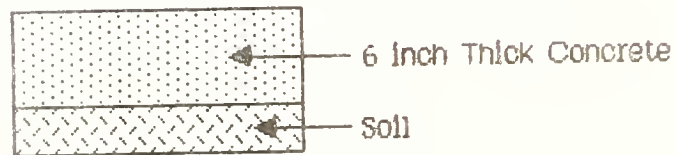


Figure 3.13 Typical Garage Floor Section

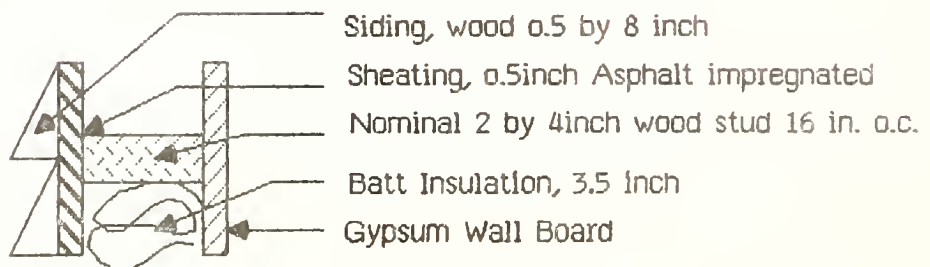


Figure 3.14 Typical Wood Siding For Office Area

In order to explain in greater detail how to fill out the BIF, the example BIF at the end of this chapter has been divided into figures. Each figure represents a portion of the BIF and is accompanied with instructions for filling out that portion of the BIF. The instructions for filling out the BIF are followed by the figure that the instructions pertain to.

A word of caution; each building is unique and therefore the information that is contained within a BIF will vary from building to building. The example building was created to try to cover the basic information that the energy auditor will be required to determine for his/her buildings. Therefore, the buildings that will be audited may or may not contain some of the information that is shown on the example.

The BIF is divided into six major sections which are identified by Roman numerals I to VI. For example, major section I covers the general description of the building. The breakdown under each major section is shown in Figure 3.15.

- I. -MAJOR SECTION I General Description
 - A. -Major Section, DIVISION A, General
 - 1. -Division A, PART 1
 - a. -Part 1, SECTION a
 - b. -Part 1, SECTION b
 - 2. -Division A, PART 2
 - a. -Part 2, SECTION a
 - b. -Part 2, SECTION b
 - B. -Major Section I, DIVISION B, Building Type

(repeated)
- II. -MAJOR SECTION II Building Characteristics

(repeated for MAJOR SECTIONS III to VI)

Figure 3.15 BIF Form Breakdown by Major Sections

Each figure has been identified with its Roman numeral major section, and what divisions within the major section are discussed in the instructions. For example, Figure 3.16 covers major section I, divisions A,B, and C for the example BIF. Figure 3.17 covers major section II of the example BIF and includes Division A, etc.

3.4.1 Major Section I, Division A,B,C

Major section I covers the general description of the building and is broken into 3 divisions. The divisions are as follows:

- * Division A General
- * Division B Building Type
- * Division C Operating Schedule

Division A is general information about the building. This portion of the BIF is straight forward with the exception of the "contact person". The contact person should be a person who works in the building or who is familiar with the construction and operation of the building. This person should be able to walk the energy auditor through the building during the site visit and answer any questions about the building he/she might have.

Division B is a brief description of the building type. Describe the major building materials used to construct the

exterior of the building. This includes the exterior walls and roof.

Next, indicate the year or approximate year the building was constructed. Year(s) and description of modification(s) pertains to any modification to the building that may have affected the energy consumption of the building. This can include such items as additional insulation, storm windows, new roofs, and additions to the building that may not be shown on the blueprints. Information about building modifications can be filled out during the site visit.

Division C is the operating schedule of the building. The times the building is in use during the day, evening, weekend and other times will be indicated. This information can be obtained during the site visit. The entries are as follows:

- Days/wk. - This refers to the number of days per week that the building is occupied. For example, in Figure 3.16 the building is occupied 5 days a week.
- Time - This refers to the time the building opens and when it closes.
- Hours - This is the total hours that the building is operated between opening and closing times.

For example, in Figure 3.16 the building is occupied 5 days a week from 8AM to 5PM. This is 9 hours a day for 5 days or 45 hours a week.

Operating

Temperature - This is the normal operating temperature (thermostat setting) during the summer and winter months.

No. of

Occupants - This refers to the average number of people who work in the building during the time specified. This may vary depending upon the time of the year and should be noted.

FORM 3.1 BUILDING INFORMATION FORM (BIF)

I General Description

A) General:

Name of Building EXAMPLE BUILDING
 Address 1ST STREET
 City WEST LAFAYETTE Telephone Number 499-0000
 District CRAWFORDSVILLE Sub-District CRAWFORDSVILLE
 Contact Person JOE Position _____
 Building use: MAINTENANCE GARAGE

B) Building Type:

Description GARAGE AREA - BRICK-BLOCK WALL
OFFICE AREA - WOOD SIDING ON WOOD STUDS
ROOF - WOOD TRUSS WITH ASPHALT SHINGLES
 Year of Construction 1970
 Year(s) and Description of Modification(s) _____
1975 - REPLACED OFFICE WINDOWS ON SOUTH
WALL WITH DOUBLE GLAZED.

C) Operating Schedule:

	Days per wk	Time from to		Hours	Operating Temperature		No. of Occupants
					SUM.	WIN.	
DAY	5	8 AM	5 PM	45	76	70	20
Evening	—	—	—	—	—	—	—
Weekend	—	—	—	—	—	—	—
Other	—	—	—	—	—	—	—

Figure 3.16 BIF Example Major Section I,
Divisions A,B, and C

3.4.2 Major Section II, Division A

Major section II covers the building characteristics and is broken into 5 divisions A, B, C, D, and E.

- * Division A Photographs of Building

- * Division B Building Floor Plans

- * Division C Floors

- * Division D Walls

- * Division E Roof

Division A will be completed during the site visit. If the building being audited has a set of blueprints, divisions B,C,D, and E can be completed prior to the site visit. If the building being audited does not have a set of blueprints, these divisions will have to be completed during the site visit.

Division A provides room for exterior photographs of the building. During the site visit photos of all sides of the building should be taken. Photographs should also be taken of building conditions that may be causing energy conservation problems. These additional photographs can be attached on separate sheets. Figure 3.17 is a representation of two photographs of the example building.

II. Building Characteristics

A) Photographs of Building:

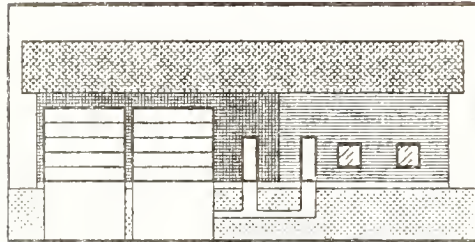
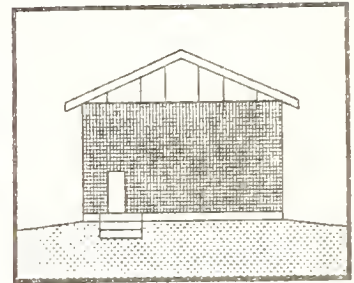
SOUTH ElevationWEST Elevation Elevation Elevation

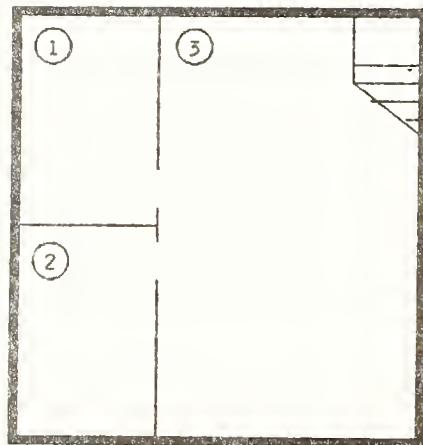
Figure 3.17 BIF Example Major Section II, Division A

3.4.3 Major Section II, Division B, Part 1 and 2

Division B is for the preparation of building floor plans. Building floor plans are prepared so that the energy auditor can enter information about the rooms in the building during the site visit. This information will include lighting layouts and location of energy conservation problems.

From the blueprints, sketch the floor plan for each floor. If a set of blueprints are not available, floor plans will have to be prepared after measuring the rooms during the site visit. The BIF has room for describing two floor plans, Part 1 and Part 2, but use as many additional sheets as needed. During the site visit, verify the floor plans prepared from the blueprints and record any major changes in the building floor plans. On the floor plan identify what each room is used for and its approximate dimensions. Figure 3.18 is the basement floor plan for the example building and Figure 3.19 is the main floor plan for the example building. The use of a numbering system to identify each room will leave enough room on the floor plan for entering the information during the site visit.

D) Building Floor Plan:

1) Floor BASEMENT

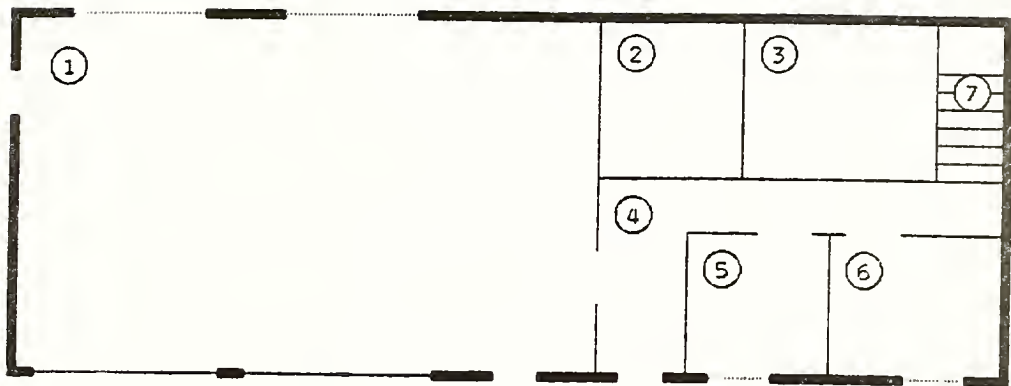
① MECH. ROOM 10' by 15'

② STORAGE ROOM 10' by 15'

③ CONFERENCE ROOM 18' by 30'

Figure 3.18 BIF Example Major Section II,
Division B, Part 1

2) Floor MAIN



① GARAGE AREA 42' by 30'

② REST ROOMS 10' by 12'

③ STORAGE 14' by 12'

④ HALL

⑤ OFFICE 10' by 10'

⑥ OFFICE 13' by 10'

⑦ STAIRS

Figure 3.19 BIF Example Major Section II,
Division B, Part 2

3.4.4 Major Section II, Division C, Part 1 and 2,
Sections a and b

Division C is for the description of the floors. There is room for describing two floors, part 1 and part 2. Section 'a' is for describing the material used in the floor construction and section 'b' is for describing the floor dimensions. For floors that are on grade or separating conditioned and unconditioned space, sketch a cross section of the floor construction. Describe the material and indicate the thickness of each material

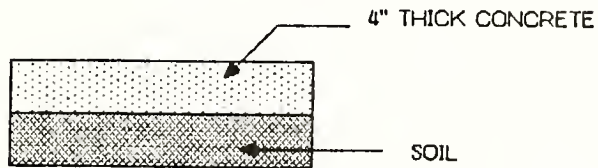
Figure 3.20 indicates the two floor sections that are identified for the example building. The basement floor is 4 inch thick concrete and is approximately 28 feet in length and 30 feet in width. The garage area is 6 inch thick concrete and is 42 feet in length and 30 feet in width. It is not necessary to identify the floor construction between the basement and the office area in this example building since both areas are conditioned space. However, if the basement in the example building were not heated then this floor would not have to be identified on the BIF. This floor would now be separating conditioned and unconditioned space and the heat loss through the floor to the basement would have to be accounted for.

C) Floors:

1) Location BASEMENT

a) Floor Construction

Description



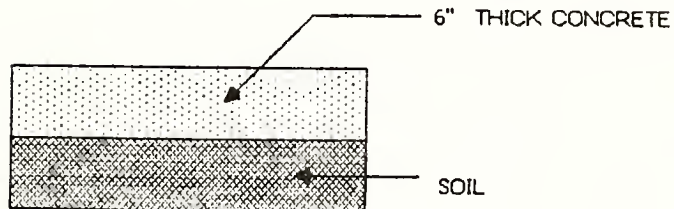
Cross Section

b) Floor Dimensions

Length 28' Width 30'2) Location GARAGE

a) Floor Construction

Description



Cross Section

b) Floor Dimensions

Length 42' Width 30'

Figure 3.20 BIF Example Major Section II, Division C,
Part 1 and 2, Section a and b

3.4.5 Major Section II, Division D, Part 1,
Sections a and b

Division D is for the description of the wall construction. There are four parts to Division D. Each part is for describing a separate wall. This will usually include the four exterior walls. However, if there is an interior wall separating conditioned and unconditioned space, it will have to be identified on the BIF. Use additional sheets if required.

Section 'a' is for describing the material used in the wall construction and for sketching the wall elevation. From the blueprints sketch a cross section through each typical wall section and describe the material and thickness. As discussed earlier, it is important to identify each typical construction within a given wall. For example, Figure 3.21, section 'a' represents the North wall cross sections of the example building. Note that for this particular wall there are three typical wall constructions. The wood siding is the exterior construction of the office area. The brick/block combination is the construction for the exterior garage walls. The concrete is the construction of the basement wall under the office area.

Next, sketch the wall elevation from the blueprints. During the site visit, inspect the exterior wall for possible energy conservation problems and note it on the sketch. This should be done for the type of information that will

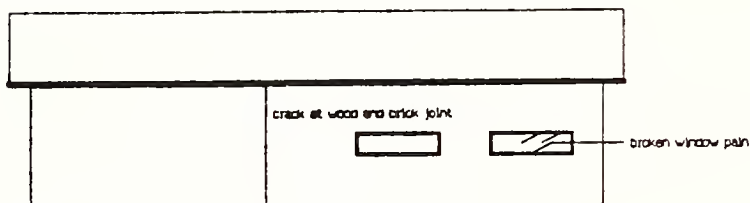
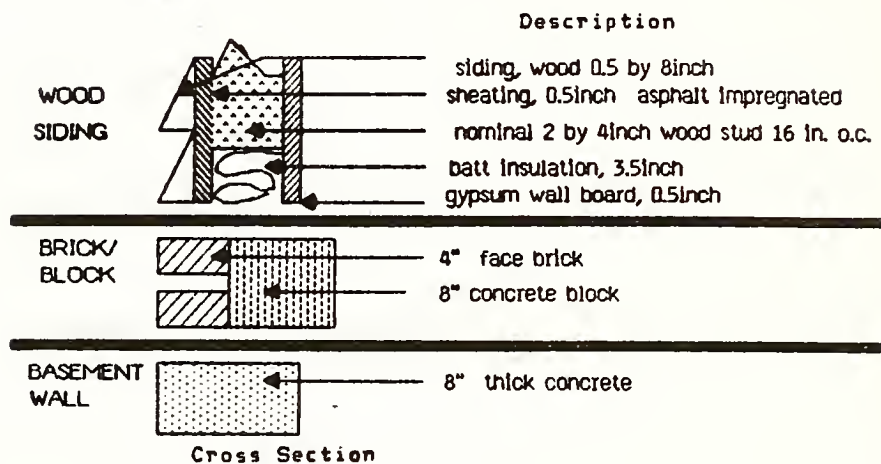
not show up in the photographs. This can include such information as condition of the sealants around windows and doors, cracks in the wall, etc. The North elevation in the example building has a broken window pane and this has been noted on the sketch, see Figure 3.21 section 'a'.

Section 'b' is for the wall construction description and dimensions. Enter a descriptive name for each wall section identified in section 'a' and enter the length and width of each wall section. Figure 3.21, section 'b' has three wall descriptions since there were three typical wall sections.

D) Walls:

1) Location NORTH

a) Wall Construction



Elevation

b) Wall Construction Description and Dimensions

Construction	<u>WOOD SIDING</u>	Length	<u>28'</u>	Height	<u>16'</u>
Construction	<u>BRICK-BLOCK</u>	Length	<u>42'</u>	Height	<u>16'</u>
Construction	<u>BASEMENT WALL</u>	Length	<u>28'</u>	Height	<u>10'</u>

Figure 3.21 BIF Example Major Section II, Division D, Section a and b

3.4.6 Major Section II, Division D, Part 1 Continued,
Sections c, d, e

Section 'c' is for describing the window construction in the exterior walls. Single, double and insulating glazed refers to the type and number of layers of glass in the window. Enter the area for each type of glazing. This area is calculated from outside to outside measurements of the window frame. The space refers to the distance in inches that separates the two layers of glass. Indicate if the windows have storm windows or any other type of window and their approximate areas. Windows may also have inside shading. This can be provided by curtains, blinds, etc. Enter the sq ft of window that the shading covers. Indicate the window frame type. This will usually be aluminum, steel or wood. Indicate the frame width in inches. The width is measured from the edge of the glass to the edge of the window frame, see Figure 3.22.

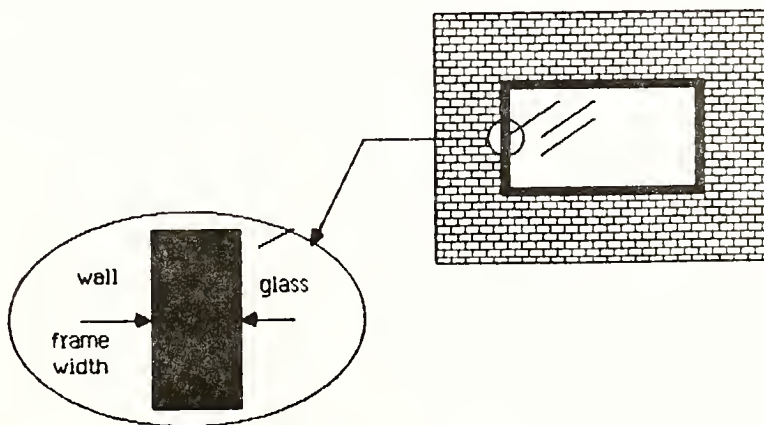


Figure 3.22 Window Frame Width Measurement

Section 'd' is for describing the door construction. The entries are as follows:

Description - Describe the door construction and type.

NO. - Indicate the number of each type of door.

Usage - Estimate the number of people per hour that use these doors. If the doors are used only in emergency situations, enter zero.

Thickness - Enter the thickness of the door in inches.

Height/Width - Enter the height and width of the door in feet and inches.

Area - Calculate the area for each door type by multiplying the NO., height, and width together.

Section 'e' is for describing the infiltration through the exterior walls. Infiltration refers to the air that enters into a building through cracks in the exterior wall, around window and door frames, and any other opening that lets air into the building where the flow of air can not be controlled. Indicate if the cracks in the exterior walls are None, Few, or Many. Indicate the condition and number of loose-fitting windows. Indicate the condition and number of loose-fitting doors. Also, indicate if the doors are properly weather stripped and the condition of the threshold. Indicate the condition of the seal between the window

air-conditioners and the building. Indicate if the exhaust ducts do not have properly working back-draft dampers. Draft dampers prevent air entering into the building when the exhaust duct is not in use. Finally, indicate any other type of crack and/or opening that lets air enter into the building uncontrolled.

Figure 3.23 is Major Section II, Division D, Part 1, Sections c, d and e. Section 'c' of Figure 3.23 indicates that the North wall of the example building has 60 square feet of singled glazed window with no shading. The window frame type is aluminum and is 2 inches wide. Section 'd' of Figure 3.23 indicates that the North wall has no doors. In some cases the exterior walls will not have any doors or windows. In these situations just fill out sections a, b, and e. Section 'e' of Figure 3.23 indicates that there is no special infiltration problems with the North wall. Generally it is expected that newer constructed buildings will have fewer infiltration problems.

c) Window Construction

Single Glazed 60 sq. ft.
 Double Glazed _____ sq. ft.
 (space) _____ inches)
 Insulating Glazed _____ sq. ft.
 (space) _____ inches)
 Storm Windows _____ sq. ft.
 Other (specify) _____ sq. ft.
 Shading (specify) N/A sq. ft.
 Window Frame Type ALUMINUM
 Frame Width 2 inches

d) Door Construction

Description	No.	Usage (Per/hr)	Thickness (inches)	Height (ft-in)	Width (ft)	Area (sf)
<u>N/A</u>	_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____	_____

e) Infiltration

Cracks through walls None X Few _____ Many _____
 Loose-fitting windows 3'x4' SECTION BROKEN
 Loose-fitting doors N/A
 Loose-fitting air conditioners N/A
 Ventilation exhaust ducts without dampers N/A
 Others observed (describe) N/A

Figure 3.23 BIF Example Major Section II, Division D, Part 1, Sections c,d, and e

3.4.7 Major Section II, Division D, Part 2,
Sections a and b

The instructions for division D, part 2 are exactly the same for part 1 of division D. Parts 3 and 4 of division D will also be the same and therefore are not included in the instructions. However, division D, parts 3 and 4, are included in the example BIF at the end of the chapter and it should noted how the information is entered for these parts. Once a wall section has been described on a previous wall section, it is not necessary to repeat the description. Figure 3.24 illustrates this point.

Section 'a' of part 2 in Figure 3.24 describes the wall section of plywood siding that occurs at the roof level on the East and West elevations. Since this type of wall construction was not described on the North wall it is necessary to describe it here.

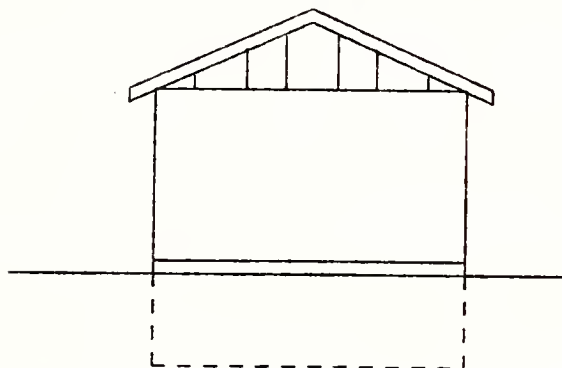
Next, notice in Figure 3.24 that there are no comments on the East elevation. This indicates that there are no noticeable problems with the East wall. Also, notice that even though the wood siding and concrete wall sections were not identified on this page, the length and width must still be entered.

2) Location EAST

a) Wall Construction

	Description
PLYWOOD SIDING	 exterior plywood sheathing, 0.5 inch nominal 2 by 4 inch wood studs 16 in. o.c. gypsum wall board, 0.5 inch
WOOD SIDING	SEE NORTH WALL WOOD SIDING DESCRIPTION
BASEMENT WALL	SEE NORTH WALL CONCRETE DESCRIPTION

Cross Section



Elevation

b) Wall Construction Description and Dimensions

Construction	<u>PLYWOOD SIDING</u>	Length	<u>15'</u>	Height	<u>8'9"</u>
Construction	<u>WOOD SIDING</u>	Length	<u>30'</u>	Height	<u>16'</u>
Construction	<u>BASEMENT WALL</u>	Length	<u>30'</u>	Height	<u>10'</u>

Figure 3.24 BIF Example Major Section II, Division D,
Part 2, Section a and b

3.4.8 Major Section II, Division E, Part 1,
Sections a, b, c, d, and e

Division E is for the description of the roof construction. There are 2 parts with five sections each. Part 1 and 2 are for describing two different roof constructions.

Section 'a' is for describing the material used in the roof construction. From the blueprints, sketch a cross section through each typical roof section. Describe the pitch of the roof, material used, and material thickness.

Section 'b' is for the dimensions of the roof described in section 'a'. Enter the width and length of the roof. This distance is measured from the outside to outside of the exterior wall. It does not include any portion of the roof that overhangs the exterior wall. If the roof is pitched, enter the distance along the pitch. See Figure 3.25 for location of measurements.

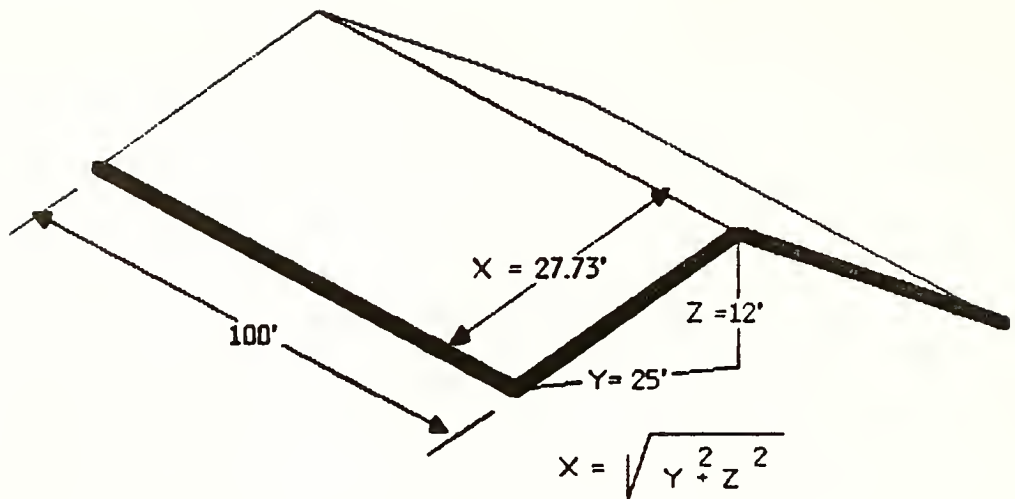


Figure 3.25 Location of Roof Measurements

Section 'c' is for describing the color and condition of the roof. The color refers to the exterior portion of the roof and for most roofs the color is usually dark. Indicate the condition of the roof and if possible determine the age of the roof. The age of the roof may give some indication of its condition.

Section 'd' is for describing skylights that may exist in the roof. From the blueprints, sketch a cross section thru a typical skylight and describe the construction.

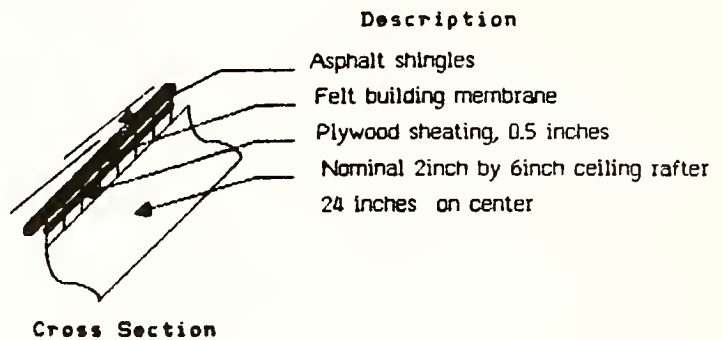
Section 'e' is for determining the area of the skylights in section 'd'. Enter the number of skylights, the length and width measured from outside to outside of the skylight frame.

Figure 3.26 is the roof section of the example building. For this example building, there is only one typical roof section and therefore part 2 is not necessary.

E) Roof:

1) Location ENTIRE BUILDING

a) Roof Construction



b) Roof Dimensions

Width 30' Length 70' Pitch 15' 8'9"

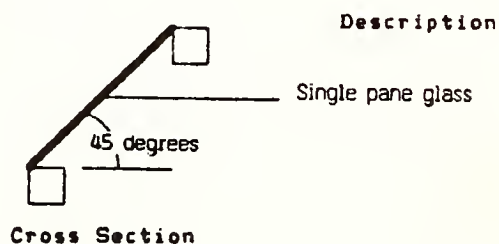
c) Roof Color and Condition

Color light _____ dark X

Condition good X fair _____ poor _____

age 14

d) Sky Lights



e) Skylight Area

No. 2 * Length 10 * Width 4 = 80 sq. ft.

No. _____ * Length _____ * Width _____ = _____ sq. ft.

Figure 3.26 BIF Example Major Section II, Division E,
Part 1, Sections a, b, c, d and e

3.4.9 Major Section III, Division A

Major Section III covers the major energy using systems and is broken into 3 divisions A,B and C.

Division A - Heating, Cooling, Hot water and
Kitchen Systems

Division B - Lighting Interior

Division C - Lighting Exterior

Division A is for describing the space heating, space cooling and hot water systems and the type of equipment that is located in the kitchen areas. A page of numbered codes follows Division A that is used for filling in the appropriate information.

Figure 3.27 indicates how this section was filled out for the example building. The energy auditor may need to consult a building systems book to familiarize himself with the different mechanical systems.

III Major Energy Using Systems

A) Fill in the appropriate numbers for items 1 thru 5 using the numbered codes listed on the next page:

	Fuel Type (A)	Mechanical Equipment (B)	Terminal Unit (C)	Thermostat Setting- F Sum. Win.	
1. Space Heating	<u>05</u>	<u>13</u>	<u>N/A</u>	<u>-</u>	<u>70</u>
2. Space Cooling	<u>02</u>	<u>22</u>	<u>N/A</u>	<u>70</u>	<u>-</u>
3. Hot Water	<u>05</u>	<u>24</u>	<u>37</u>	<u>110°</u>	<u>110°</u>
4. Kitchen	<u>N/A</u>	<u>N/A</u>	<u>N/A</u>	<u>N/A</u>	<u>N/A</u>
5. Kitchen equipment description _____					

Figure 3.27 BIF Example Major Section III, Division A

3.4.10 Major Section III, Division B

Division B is for a lighting survey of the interior. During the site visit use the floor plans that have been prepared from either the blueprints or from a building survey to enter information about the lighting systems. This information will then be used to evaluate the lighting system using the procedures discussed in Chapter 6.

On the floor plan for each room indicate the following:

* the number of fixtures in use

* the ceiling height for each room

- * the fixture height (distance from floor to bottom of fixture)
- * number of lamps per fixture
- * lamp abbreviation number (see Chapter 6 section 6.2.1)
- * the footcandle level for several locations in the room.

The footcandles can be measured with a light meter described in the equipment section of the site visit procedures, see Chapter 4 section 4.2.

Figure 3.28 is the basement floor plan of the example building after the lighting information has been filled out. If the floor plan is large enough, the energy auditor should indicate the light fixture locations. This information will be useful in determining what fixtures to eliminate if the lighting levels can be reduced. This will be discussed further in Chapter 6.

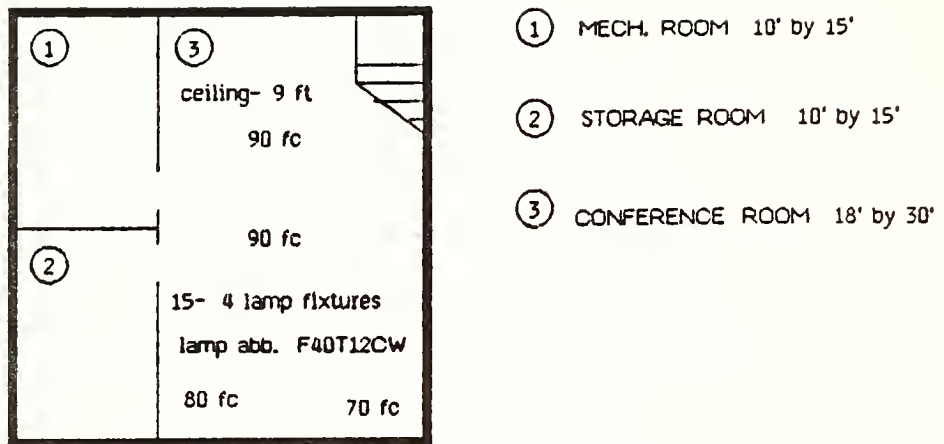


Figure 3.28 Example Building Basement Floor Plan With Lighting Information

After the energy auditor has completed the site visit, he/she can finish the lighting survey back at the office. This will involve the transfer of information from the floor plans to Division B of Major Section III and some simple calculations. The entries and calculations are as follows:

Room -	Enter a descriptive name of the room.
Area -	Enter the area of each room in square feet.
Ceil Hght. -	Enter the ceiling height in feet.
Fix. Hght. -	Enter the fixture height in feet.
Total Watts -	Calculate the total watts for each room. The total watts is the number of fixtures times the watts per fixture. See Chapter 6

section 6.2.1 for determining the watts per lamp of a fluorescent fixture. For example, the conference room in the basement has 15 fixtures with 4 lamps each at 46 watts per lamp. The total watts per fixture is 4 times 46 watts or 184 watts per fixture. Therefore, the total watts for the conference room is 15 fixtures times 184 watts per fixture or 2,760 total watts.

Avg. Lgt. Lev. - Calculate the average lighting level in the room. This is the total number of footcandles divide by the number of measurements. For example, the conference room had a total of 330 footcandles from 4 measurements or an average level of 82.5 footcandles.

B) Lighting Interior:

Room	Area (sf.)	Ceil. Hght. (ft.)	Fix. Hght. (ft.)	Total Watts	Avg. Lgt. Lev. (fc)	Usage (hrs/wk)
MECHANICAL	150	10	9		20	N/A
STORAGE	150	10	9		10	N/A
CONFERENCE	540	9	9	2760	82.5	8
GARAGE	1260	16	14	4860	73	45
REST ROOMS	120	8	8	368	50	10
STORAGE	168	10	9	276	30	5
HALL		9	9		50	N/A
OFFICE	100	8	8	368	80	45
OFFICE	130	8	8	460	83	45
STAIRS						

Figure 3.29 BIF Example Major Section III, Division B

3.4.11 Major Section III, Division C,

Division C is for a lighting survey of the exterior lighting. Part 1 is for the perimeter lighting of the building and part 2 is for the parking area. The major concern with the exterior lighting is the method of control or how the lights are turned on and off. The information for this section can be placed directly on the BIF. The entries for the perimeter and the parking area are as follows:

Location - Enter the location of the light(s).

Type - Enter the type of light fixture.

Total-watts - Enter the total watts for the location.

Method-of-control - Describe how the lights are activated.
Manual, Photocell, Timer or Other
(specify)

Usage - Determine the average hours per week
that the lights are on.

C) Lighting Exterior:

1) Building Perimeter

Location	Type	Total Watts	Method of control	Usage (hrs/wk)
<u>WEST</u>	<u>FLOOD</u>	<u>2000</u>	<u>MANUAL</u>	<u>118</u>
<u>SOUTH</u>	<u>FLOOD</u>	<u>5000</u>	<u>MANUAL</u>	<u>118</u>
<u> </u>	<u> </u>	<u> </u>	<u> </u>	<u> </u>
<u> </u>	<u> </u>	<u> </u>	<u> </u>	<u> </u>

2) Parking Area

Location	Type	Total Watts	Method of control	Usage (hrs/wk)
<u>SOUTH</u>	<u> </u>	<u>20000</u>	<u>MANUAL</u>	<u>50</u>
<u> </u>	<u> </u>	<u> </u>	<u> </u>	<u> </u>
<u> </u>	<u> </u>	<u> </u>	<u> </u>	<u> </u>
<u> </u>	<u> </u>	<u> </u>	<u> </u>	<u> </u>

Figure 3.30 BIF Example Major Section III, Division C

3.4.12 Major Section IV

Major section IV is for entering the climatic data that will be used in Chapter 5 for the heat loss calculations. The climatic data is provided for Indiana cities by district in Table 3.1. Select the city nearest to the building being audited and enter the necessary climatic data. A heating degree-day (HDD) is an average temperature 1° below a 65°F base over a 24-hour period. For example, a day with an average temperature of 50°F would have 15 heating degree-days. A cooling degree-day (CDD) is an average temperature 1°F over a 65°F base. Heating degree-days and cooling degree-days are one parameter used to estimate fuel consumption.

IV. Climatic Data

Outside Temperature (winter)	<u>30°F</u>
Average Annual Heating Degree Days	<u>5755</u>
Average Annual Cooling Degree Days	<u>983</u>
Main Wind Direction and Velocity	<u>NORTH / 10 MPH</u>

Figure 3.31 BIF Example Major Section IV

Table 3.1 Climatic Data for Indiana

District/ City	Outside ^a Temperature ° F	AVG Annual HDD	AVG Annual CDD	AVG Winter Wind Vel. MPH
CRAWFORDSVILLE				10
Crawfordsville	3	5755	983	
Lafayette	3	5351	1110	
Terre Haute	4	6223	818	
FORT WAYNE				15
Fort Wayne	1	6209	748	
Goshen	1	6272	708	
Huntington	1	5914	830	
Marion	0	6125	794	
Peru	-1	5585	1081	
GREENFIELD				10
Anderson	6	5580	981	
Indianapolis	2	5577	974	
Kokomo	0	5585	1081	
Muncie	2	5500	900	
Richmond	2	5897	702	
Shelbyville	3	5399	1025	
LAPORTE				15
Laporte	3	6349	796	
Gary	2	6036	830	
Hobart	2	6036	830	
South Bend	1	6462	695	
Valparaiso	3	6277	705	

Table 3.1 Continued

District/ City	Outside Temperature ° F	AVG Annual HDD	AVG Annual CDD	AVG Winter Wind Vel. MPH
SEYMOR				10
Bloomington	5	4905	1177	
Columbus	7	5266	889	
Jeffersonville	10	4132	1461	
New Albany	10	4132	1416	
Seymor	6	5187	1137	
VINCENNES				10
Bedford	5	4790	1139	
Evansville	9	4624	1364	
Vincennes	6	4946	1295	

a

Outside design winter weather condition temperature, Design Dry-Bulb at 97.5%.

3.4.13 Major Section V

Major Section V pertains to existing energy management programs. This section can be filled out during the site visit with the assistance of the contact person.

3.4.14 Major Section VI

Major Section VI is for field inspection notes taken during the site visit. These notes should contain any information about the building that will help clarify the information contained in the BIF or clarify any possible energy conservation opportunities.

Note: The rest of Chapter 3 is Form 3.1 Building Information Form (BIF) filled out for the example building shown in Figures 3.3 to 3.4. This is an example of how a completed BIF would appear.

FORM 3.1 BUILDING INFORMATION FORM (BIF)

I. General Description

A) General:

Name of Building EXAMPLE BUILDING
 Address 1ST STREET
 City WEST LAFAYETTE Telephone Number 499-0000
 District CRAWFORDSVILLE Sub-District CRAWFORDSVILLE
 Contact Person JOE Position _____
 Building use: MAINTENANCE GARAGE

B) Building Type:

Description GARAGE AREA - BRICK-BLOCK WALL
OFFICE AREA - WOOD SIDING ON WOOD STUDS
ROOF - WOOD TRUSS WITH ASPHALT SHINGLES
 Year of Construction 1970
 Year(s) and Description of Modification(s) _____
1975 - REPLACED OFFICE WINDOWS ON SOUTH
WALL WITH DOUBLE GLAZED.

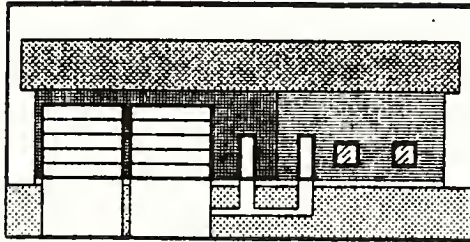
C) Operating Schedule:

	Days per wk	Time from to	Hours	Operating Temperature		No. of Occupants
				SUM.	WIN.	
DAY	5	8AM - 5PM	45	76	70	20
Evening	_____	_____ - _____	_____	_____	_____	_____
Weekend	_____	_____ - _____	_____	_____	_____	_____
Other	_____	_____ - _____	_____	_____	_____	_____

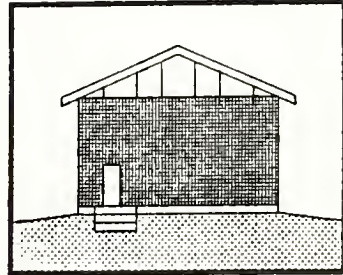
Figure 3.32 Form 3.1 Building Information Form (BIF)
Example

II. Building Characteristics

A) Photographs of Building:



SOUTH Elevation



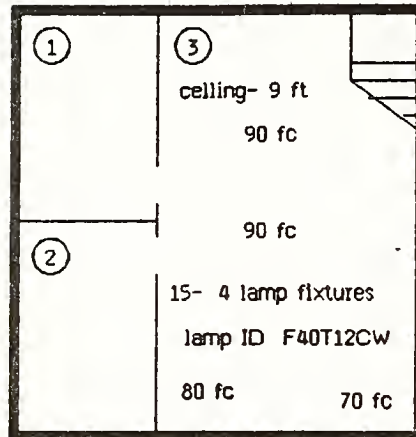
WEST Elevation

_____ Elevation

_____ Elevation

Figure 3.32 Continued

B) Building Floor Plan:

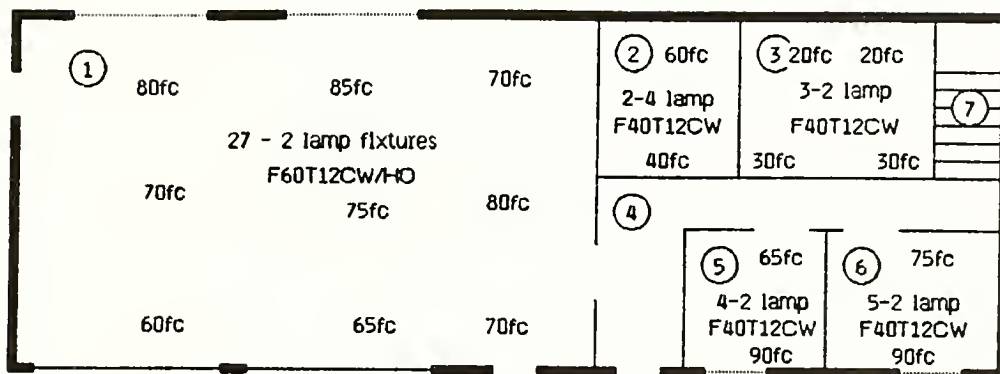
1) Floor BASEMENT

① MECH. ROOM 10' by 15'

② STORAGE ROOM 10' by 15'

③ CONFERENCE ROOM 18' by 30'

Figure 3.32 Continued

2) Floor MAIN

① GARAGE AREA 42' by 30'

⑤ OFFICE 10' by 10'

② REST ROOMS 10' by 12'

⑥ OFFICE 13' by 10'

③ STORAGE 14' by 12'

⑦ STAIRS

④ HALL

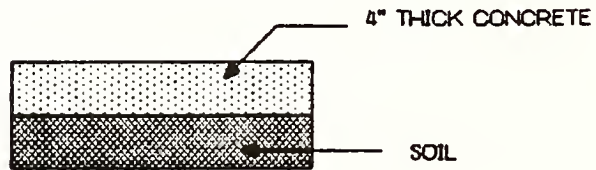
Figure 3.32 Continued

C) Floors:

1) Location BASEMENT

a) Floor Construction

Description



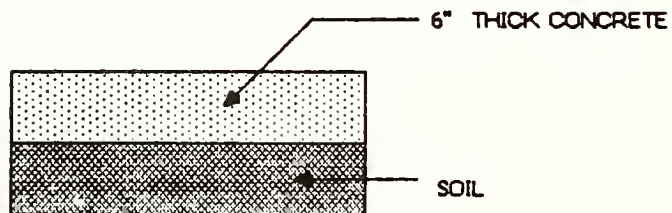
Cross Section

b) Floor Dimensions

Length 28' Width 30'2) Location GARAGE

a) Floor Construction

Description



Cross Section

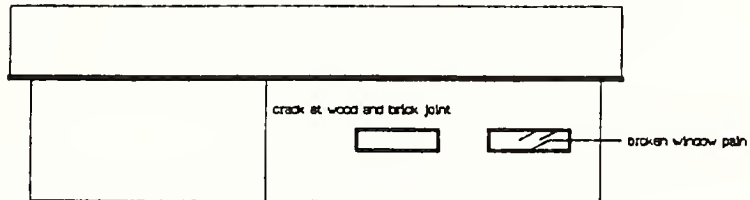
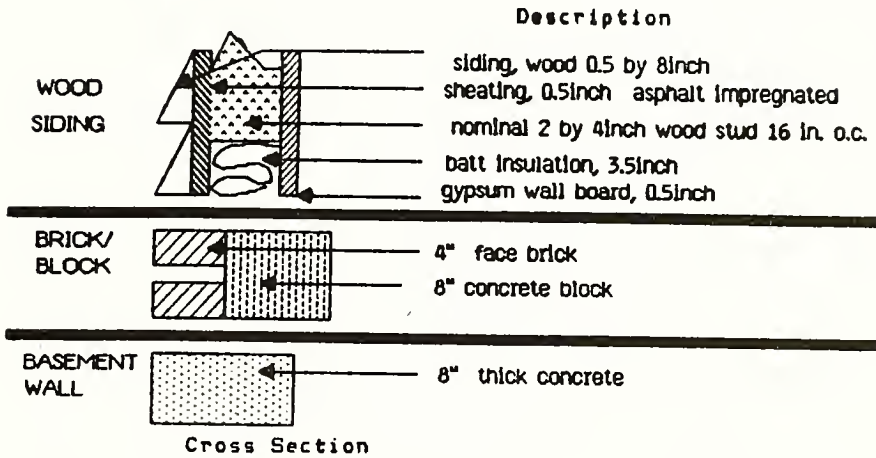
b) Floor Dimensions

Length 42' Width 30'

D) Walls:

1) Location NORTH

a) Wall Construction



Elevation

b) Wall Construction Description and Dimensions

Construction WOOD SIDING Length 28' Height 16'

Construction BRICK - BLOCK Length 42' Height 16'

Construction BASEMENT WALL Length 28' Height 10'

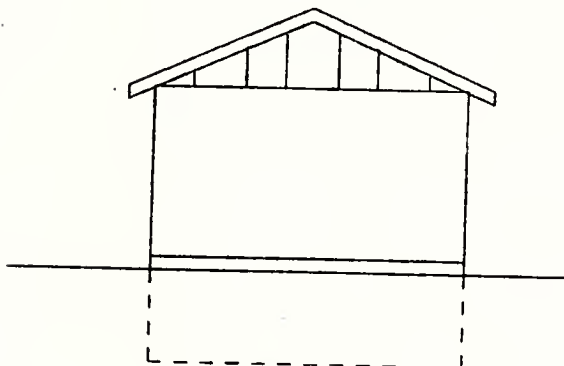
Figure 3.32 Continued

2) Location EAST

a) Wall Construction

	Description
PLYWOOD SIDING	 exterior plywood sheathing, 0.5 inch nominal 2 by 4 inch wood studs 16 in. o.c. gypsum wall board, 0.5 inch
WOOD SIDING	SEE NORTH WALL WOOD SIDING DESCRIPTION
BASEMENT WALL	SEE NORTH WALL CONCRETE DESCRIPTION

Cross Section



Elevation

b) Wall Construction Description and Dimensions

Construction	<u>PLYWOOD SIDING</u>	Length	<u>15'</u>	Height	<u>8'9"</u>
Construction	<u>WOOD SIDING</u>	Length	<u>30'</u>	Height	<u>16'</u>
Construction	<u>BASEMENT WALL</u>	Length	<u>30'</u>	Height	<u>10'</u>

Figure 3.32 Continued

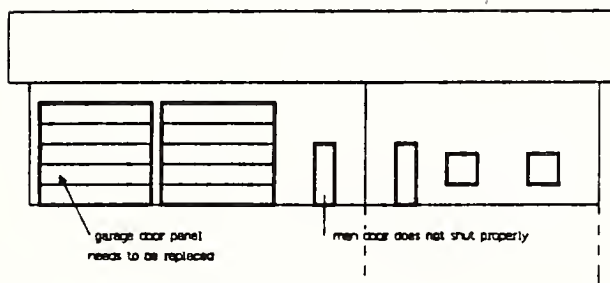
3) Location SOUTH

a) Wall Construction

Description

(SEE NORTH WALL DESCRIPTIONS)

Cross Section



Elevation

b) Wall Construction Description and Dimensions

Construction	<u>WOOD SIDING</u>	Length	<u>28'</u>	Height	<u>16'</u>
Construction	<u>BRICK-BLOCK</u>	Length	<u>42'</u>	Height	<u>16'</u>
Construction	<u>BASEMENT WALL</u>	Length	<u>28'</u>	Height	<u>10'</u>

Figure 3.32 Continued

4) Location WEST

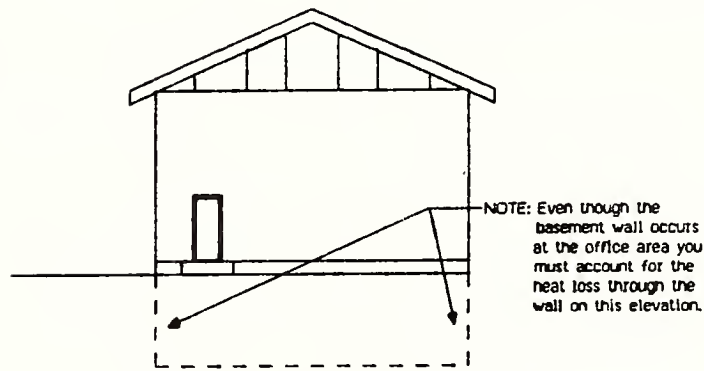
a) Wall Construction

Description

(SEE EAST WALL FOR PLYWOOD SIDING
AND CONCRETE)

(SEE NORTH WALL FOR BRICK-BLOCK)

Cross Section



Elevation

b) Wall Construction Description and Dimensions

Construction	<u>PLYWOOD SIDING</u>	Length	<u>15'</u>	Height	<u>8'9"</u>
Construction	<u>BRICK-BLOCK</u>	Length	<u>30'</u>	Height	<u>16'</u>
Construction	<u>BASEMENT WALL</u>	Length	<u>30'</u>	Height	<u>10'</u>

Figure 3.32 Continued

c) Window Construction

Single Glazed	_____	sq. ft.
Double Glazed	_____	sq. ft.
(space	_____	inches)
Insulating Glazed	_____	sq. ft.
(space	_____	inches)
Storm Windows	_____	sq. ft.
Other (specify) _____	_____	sq. ft.
Shading (specify) _____	_____	sq. ft.
Window Frame Type _____		
Frame Width	_____	inches

d) Door Construction

Description	No.	Usage (Per/hr)	Thickness (inches)	Height (ft-in)	Width (ft)	Area (sf)
METAL-MAN	1	N/A	N/A	7'	3'	21

e) Infiltration

Cracks through walls None _____ Few _____ Many _____

Loose-fitting windows _____

Loose-fitting doors _____

Loose-fitting air conditioners _____

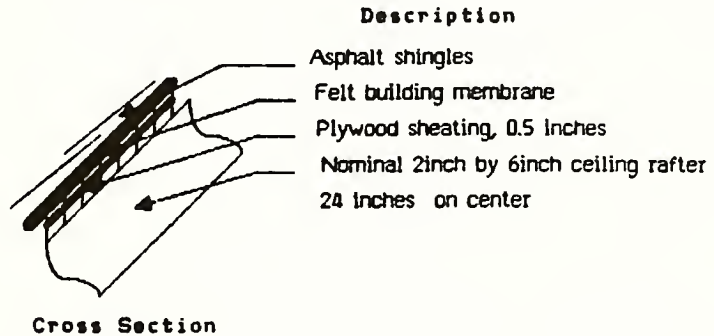
Ventilation exhaust ducts without dampers _____

Others observed (describe) _____

E) Roof:

1) Location ENTIRE BUILDING

a) Roof Construction



b) Roof Dimensions

Width 30' Length 70' Pitch 15' 8'9"

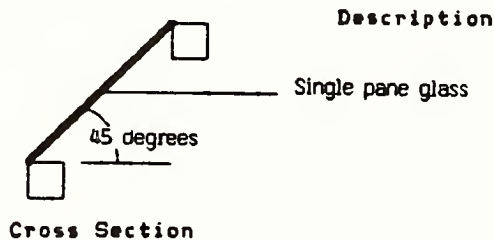
c) Roof Color and Condition

Color light _____ dark X

Condition good X fair _____ poor _____

age 14

d) Sky Lights



e) Skylight Area

No. 2 * Length 10 * Width 4 = 80 sq. ft.

No. _____ * Length _____ * Width _____ = _____ sq. ft.

2) Location _____

a) Roof Construction

Description

Cross Section

b) Roof Dimensions

Width _____ Length _____

c) Roof Color and Condition

Color light _____ dark _____

Condition good _____ fair _____ poor _____

d) Sky Lights

Description

Cross Section

e) Sky Light Area

No. _____ * Length _____ * Width _____ = _____ sq. ft.

No. _____ * Length _____ * Width _____ = _____ sq. ft.

III. Major Energy Using Systems

A) Fill in the appropriate numbers for items 1 thru 5 using the numbered codes listed on the next page:

	Fuel Type(A)	Mechanical Equipment (B)	Terminal Unit (C)	Thermostat Setting- F	
				Sum.	Win.
1. Space Heating	<u>05</u>	<u>13</u>	<u>N/A</u>	<u>-</u>	<u>70</u>
2. Space Cooling	<u>02</u>	<u>22</u>	<u>N/A</u>	<u>70</u>	<u>-</u>
3. Hot Water	<u>05</u>	<u>24</u>	<u>37</u>	<u>110°</u>	<u>110°</u>
4. Kitchen	<u>N/A</u>	<u>N/A</u>	<u>N/A</u>	<u>N/A</u>	<u>N/A</u>
5. Kitchen equipment description _____					

A. Fuel Type:

01 Coal	06 Propane
02 Electricity	07 Purchased Steam
03 No. 2 Fuel Oil	08 Wood
04 No. 6 Fuel Oil	09 Other (specify) _____
05 Natural Gas	

B. Mechanical Equipment:

Heating System	Cooling System	Hot Water System
10 Low pressure steam boiler	17 Absorption	24 Hot water heater
11 High pressure steam boiler	18 Centrifugal	25 Boiler heat exchanger
12 Hot water boiler	19 Reciprocating	26 Booster/reheat
13 Forced air furnace	20 Window/wall unit	27 Solar assisted
14 Resistance	21 Heat pump	28 Other _____ (specify)
15 Heat pump	22 Other <u>CENTRAL AIR</u> (specify)	
16 Other _____ (specify)		

C. Terminal Units

29 Radiator	33 Dual duct	37 Self-contained
30 Fan coil/radiator	34 Variable air vol.	38 Circulating
31 Single zone	35 Induction	39 Non-circulating
32 Multi-zone	36 Terminal unit	40 Other _____ (specify)

D. Efficiency analysis

Unit Description _____

Nameplate _____ Nameplate _____
 Output(BTU/hr) _____ Input(BTU/hr) _____ = Efficiency _____ %

Unit Description _____

Nameplate _____ Nameplate _____
 Output(BTU/hr) _____ Input(BTU/hr) _____ = Efficiency _____ %

Unit Description _____

Nameplate _____ Nameplate _____
 Output(BTU/hr) _____ Input(BTU/hr) _____ = Efficiency _____ %

B) Lighting Interior:

[illegible]

Figure 3.32 Continued

C) Lighting Exterior:

1) Building Perimeter

Location	Type	Total Watts	Method of control	Usage (hrs/wk)
<u>WEST</u>	<u>FLOOD</u>	<u>2000</u>	<u>MANUAL</u>	<u>118</u>
<u>SOUTH</u>	<u>FLOOD</u>	<u>5000</u>	<u>MANUAL</u>	<u>118</u>
<u> </u>	<u> </u>	<u> </u>	<u> </u>	<u> </u>
<u> </u>	<u> </u>	<u> </u>	<u> </u>	<u> </u>

2) Parking Area

Location	Type	Total Watts	Method of control	Usage (hrs/wk)
<u>SOUTH</u>	<u> </u>	<u>20000</u>	<u>MANUAL</u>	<u>50</u>
<u> </u>	<u> </u>	<u> </u>	<u> </u>	<u> </u>
<u> </u>	<u> </u>	<u> </u>	<u> </u>	<u> </u>
<u> </u>	<u> </u>	<u> </u>	<u> </u>	<u> </u>

IV. Climatic Data

Outside Temperature (winter) 30°F
 Average Annual Heating Degree Days 5755
 Average Annual Cooling Degree Days 983
 Main Wind Direction and Velocity NORTH / 10 MPH

V. Description of Energy Management Activities

Energy Management Team Formed Yes _____ NO X

Energy Management Coordinator Designated Yes _____ NO X

Energy Audit Completed _____ Started X None _____

Detailed Study by Architect or Engineer

Completed _____ Started _____ None X

Energy Management Measures Implemented and Dates

VI. Field Inspection Notes

CHAPTER 4 BUILDING SITE VISIT

4.1 Introduction

A building site visit enables the energy auditor to finish filling in the information requested on the BIF and to become familiar with the operating conditions of the building. However, keep in mind that this is a one day observation and operating conditions change from day to day and season to season.

Arrangements for the building site visit should be made after completing as much of the BIF as possible. Preferably the site visit should be done during regular business hours. However, if it is necessary to do a complete building survey the energy auditor may wish to arrange a time when the building will not be occupied. This will allow ample time for making the necessary measurements and investigations of the building for completing the building survey. See section 4.4 for general instructions on completing the building survey. After the energy auditor has completed the building survey, arrangements should be made for completing the site visit during the normal business hours. This will allow him to inspect the facility under normal operating conditions.

4.2 Required Material to Complete the Building Site Visit

- * Form 3.1 Building Information Form (BIF)
- * Clip board with paper and pencil
- * 50 and 12 ft. tape measures
- * flashlight
- * light meter
- * 35 mm camera
- * thermometer
- * contact thermometer

With the exception of the light meter and contact thermometer the equipment should be readily available. A light meter can be purchased from the following companies:

General Electric
Lamp Business Division
Nela Park
Cleveland, OH 44112
Phone (216) 266-2121

Huygen Corporation
P. O. Box 316
Wauconda, IL 60084
Phone (312) 381-4050

It is highly recommended that each auditor obtain a light meter since an important part of the lighting survey

is to determine existing lighting levels. However, a light meter is not mandatory for completing the lighting survey.

The contact thermometer or surface pyrometer is used in assessing heat losses through walls when the material in the wall can not be identified. There are two classes of surface pyrometers. The first class is good to temperatures of 250 deg F and the second class is good for temperatures up to 600-700 deg F. The first class surface pyrometer will be more than sufficient for this energy auditing process. A surface pyrometer can be purchased from the following companies:

Alnor Instrument Company
7301 N. Caldwell Avenue
Niles, IL 60648
Phone (312) 647-7866

4.3 Procedures for Completing the Site Visit

During the site visit the energy auditor will be gathering data and inspecting the building to determine what energy conservation opportunities (ECOs) exist. ECOs are divided into two groups. The first group are the noncapital type; implementing noncapital ECOs involves little, if any, monetary expense. The second group are of the capital type, and to implement a capital ECO requires the outlay of money. Therefore, for capital ECOs, an economic analysis must be completed to determine which capital ECOs are economically

feasible. The economic analysis procedure for capital ECOs is covered in Chapter 8.

Several of the noncapital ECOs that exist can be determined by visual inspection. A check list of possible non-capital ECOs can be found in Appendix B. During the site visit, simply check off the items pertaining to the building being audited. This list is not inclusive of all energy conservation measures, but will give the energy auditor a good idea of the type of items to be looking for during the site visit.

4.3.1 Interior Building Inspection

After meeting with the contact person and having any questions answered about the building from reviewing the blueprints, a walk-through of the building's interior should begin. Begin at one end of the building and do a room by room inspection of the building. For each room, mark the necessary information on the floor plan sketches that have been prepared beforehand. The following items require visual inspection in order to determine their condition and can not be determined from the blueprints. Note the condition of the following items on the the floor plan sketches.

A. Window Construction

* Inspect the windows for cracks between the window

frame and the wall and between the windows' operable sections.

- * Inspect windows for broken panes.
- * Inspect windows for curtains, blinds, etc. for shading.
- * Identify window frame type and width.
- * Verify the window types as described on the blueprints and note any changes.

B. Door Construction

- * Inspect doors for weather stripping and the condition of the thresholds.
- * Inspect the bottom gasket seal on garage doors.
- * Verify the door types described on the blueprints and note any changes.

C. Infiltration

- * Inspect the exterior walls on the inside for cracks or openings.
- * Inspect the exhaust ducts for proper back draft dampers.

D. Lighting System

- * Identify the type of light fixtures and lamps, see Chapter 6.
- * Determine the number of light fixtures in use.
- * Determine if ballasts have been disconnected for light fixtures not in use.
- * Measure the average footcandles with the light meter in three or four locations. More measurements may be required for larger areas. This is the only section of the lighting survey that can not be completed without a light meter.
- * Verify the lighting system layout and note any changes from the blueprints.

E. General Inspection

- * Photograph any unusual conditions within the building that are causing excessive energy waste.
- * Ask the people who work in the building if they have any comments about the operating conditions of the building, such as, drafts in the winter, lighting levels too low to high, lighting or windows causing glare on the task plane, etc.

- * Identify the major equipment used in the building.
- * Inspect the overall conditions of walls, floors, and light fixtures for dirt and dust. Clean walls, floors and light fixtures will improve the lighting systems performance.

4.3.2 Exterior Building Inspection

After completing the interior building inspection, the energy auditor should then inspect the building exterior. The main concerns with the exterior inspection is the condition of the building's walls and roof. The following items should be identified on the BIF or on the building elevation sketches prepared beforehand.

A. Exterior Walls

- * Photograph all sides of the building.
- * Inspect the exterior walls for cracks or openings and loose construction joints.
- * Inspect the windows for cracks between the window frame and the exterior siding.
- * Verify the building component descriptions obtained from the blueprints and note any changes, i.e. room additions, additional insulation, etc.

B. Roof

- * Inspect the roof to determine its color and condition
- * Identify the major equipment on the roof
- * Inspect any skylights
- * Verify the roof dimensions and the material used in the construction and note any changes.

By following the outline of the building information form (BIF) and filling it out as the building is inspected, the proper information to do an energy audit will be obtained. It may also be a good idea to rewrite the field inspection notes after getting back to the office. This will help to clarify the information and may also prompt the energy auditor to remember items forgotten during the site visit.

4.4 Procedures for Completing a Building Survey

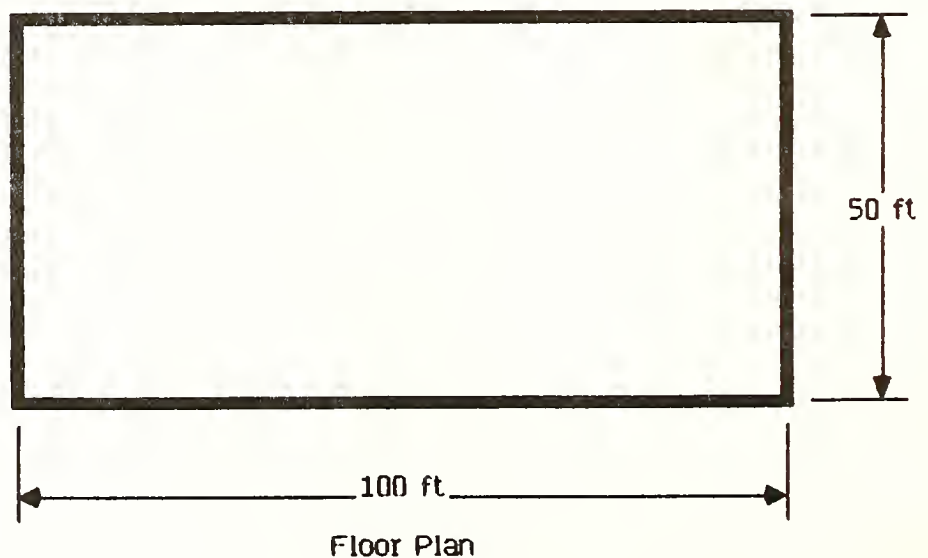
The building survey is necessary when the building being audited does not have a set of existing blueprints. The purpose of the building survey is to determine the same information available from a set of architectural blueprints. This includes the physical dimensions, material identification, and major energy using systems of the building. It is strongly suggested that the inexperienced energy auditor

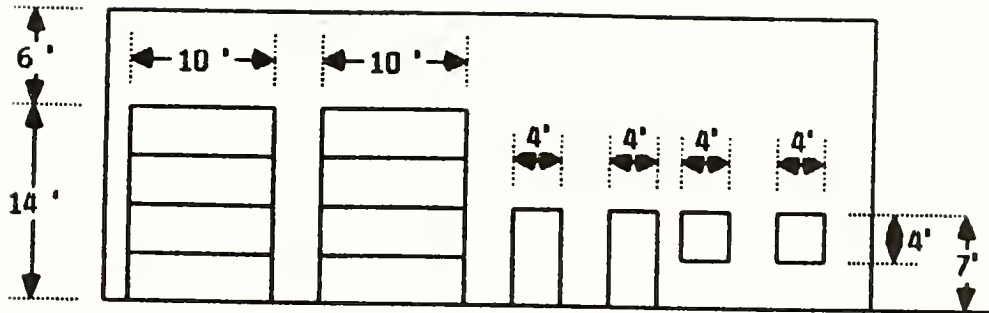
does not audit a building for the first time without a set of blueprints. After he/she has audited a building, he/she will know what building dimensions, material identification and major energy using systems are important to identify.

4.4.1 Determining Building Dimensions

Measure the building components that are experiencing heat loss as identified in Figure 3.2 of Chapter 3. The accuracy of the measurements is not critical, but each typical building component, i.e. walls, doors, windows, must be measured. The following general steps should be followed in measuring the building dimensions.

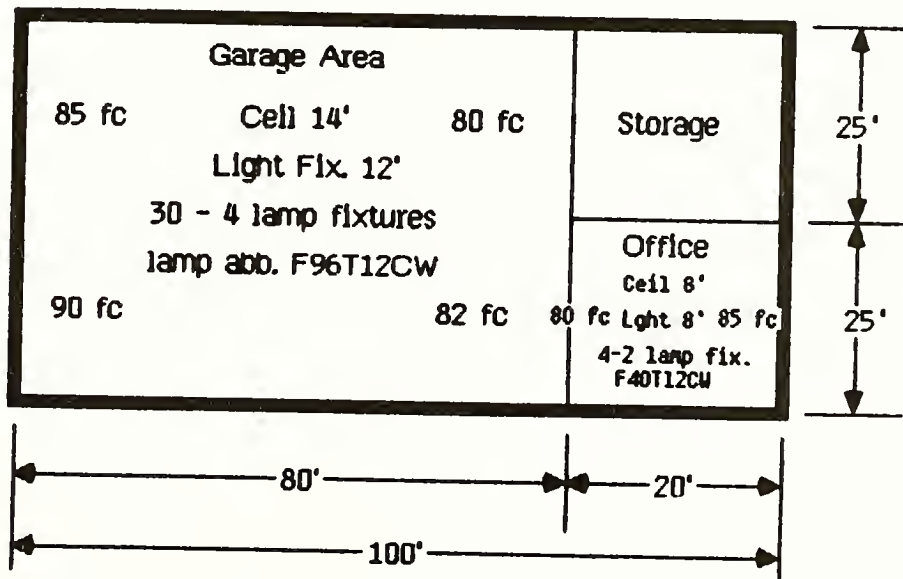
STEP 1: Sketch the building floor outline and enter the dimensions. These sketches can be drawn directly on the BIF.



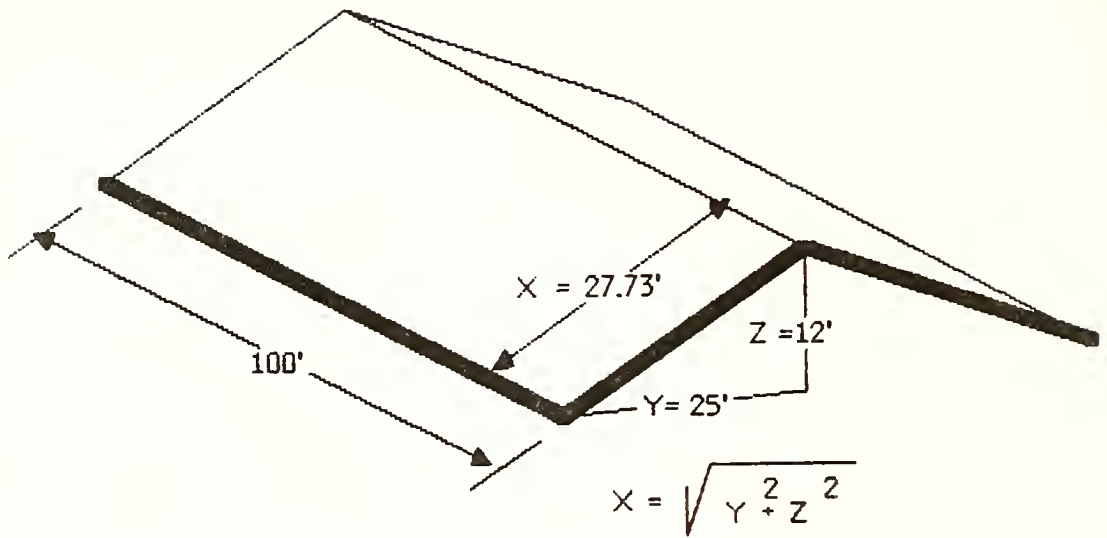


West Elevation

STEP 2: Sketch the building elevations and identify the doors and windows. Enter the dimensions.



STEP 3: Sketch the rooms on the floor plan sketch from step 1. Identify the rooms, ceiling heights and fixture heights.



STEP 4: Sketch the roof and measure the length, width and pitch.

4.4.2 Building Material Identification

Identifying the material used in constructing the building is necessary for determining the thermal properties of the building's materials. Again, the energy auditor should only be concerned with identifying the material in the components experiencing heat loss as identified in Chapter 3. For each typical building material, identify its composition and thickness. It is not difficult to determine the composition of the exterior and interior material that can be viewed with the naked eye. However, it may be very difficult to determine the thickness of the material. For the material on the interior of the building component, it may be impossible to determine its composition and thickness. If the thickness or the composition of a building material cannot be identified, then it is impossible to calculate its R value and U coefficient without first measuring the indoor and outdoor air temperatures and the inside surface temperature of the building component.

For buildings that the building components can be identified by visual inspection, prepare sketches for each typical component and identify its composition and the thickness of each material. For buildings that the building components can not be identified by visual inspection, the energy auditor can determine the U coefficient for walls with the following method [2].

STEP 1: Measure the indoor and outdoor air temperatures with an accurately calibrated thermometer on a sunless day or at night.

STEP 2: Measure at the same time the inside surface temperature of the wall with an accurately calibrated contact thermometer.

STEP 3: Calculate the rate of heat flow through the wall with the inside air temperature, inside surface temperature, and the inside film coefficient. The inside film coefficient is described in Chapter 5 in section 5.2. Values of the inside film coefficient can be found in Table 5.2 of Chapter 5. The heat flow is calculated using Eq. 4.1 as follows:

$$\text{Heat flow} = \frac{\text{inside air temp.} - \text{inside surface temp.}}{\text{inside film coefficient}} \quad (4.1)$$

STEP 4: Using the calculated rate of heat flow, now calculate the overall U value using formula 4.2:

$$U = \frac{\text{heat flow}}{\text{inside air temperature} - \text{outside air temperature}} \quad (4.2)$$

For example, determine the U coefficient for an exterior wall with the following conditions:

Inside air temperature	68 °F
Outdoor temperature	20 °F
Inside wall surface temperature	59.4 °F

Inside film coefficient,
from Table 5.2

0.68

$$\text{Rate of heat flow} = \frac{68 - 59.4}{0.68} = 12.65 \text{ Btu/h}$$

$$\text{Overall U value} = \frac{12.6}{68 - 20} = 0.263$$

This calculation procedure would be repeated for each typical exterior wall section. During the building survey it is only necessary to enter the temperature readings and the locations on the wall sketches. The calculations can be completed at a later time. It is also a good idea to take several readings at different locations for each typical wall section. This will allow an average U value to be calculated and will be more accurate than a single reading.

This method does not enable the U coefficient of the roof or floors to be calculated. Generally, if a roof has an attic, identifying the building materials is not too difficult. To determine the U coefficient for floors may require an approximation based from similar type floors where the U value is known.

4.4.3 Major Energy Using Systems Identification

Identifying the building's major energy using systems, such as the heating and lighting systems, is not too difficult for buildings without a set of existing blueprints. In

most cases, the majority of the older buildings will not have the original energy using systems as identified on the original blueprints. By completing major section III of the BIF, the energy auditor will identify by visual inspection the major energy using systems that are necessary for completing the energy audit.

CHAPTER 5 HEAT LOSS CALCULATIONS

5.1 Introduction

The basic principles of heat transfer will be used to determine the amount of heat that is lost from a building during the heating season. Indiana's heating season on the average is from October to May. This will vary from year to year and location to location within the state. The amount of heat that is lost during the heating season is a function of many variables. This manual will be concerned with the major contributing variables to heat loss during the heating season. To account for all the heat losses within a given facility is beyond the scope of this manual. By focusing on the major variables, a good understanding of how a building losses heat during the winter will be gained.

After a building's heat losses have been calculated, it is possible to calculate the fuel consumption of the building during the heating season. The calculated energy consumption can then be compared to the actual energy consumption. This will make it possible to determine if the building components have been properly identified and the heat loss calculations completed properly. In order to evaluate

energy conservation alternatives from an economic standpoint, the existing condition of the building must be known in order to determine what impact the ECOs will have on energy consumption.

Heat is lost from a building via transmission and infiltration. Determination of these heat losses is a major step in the energy audit process. It will enable the energy auditor to determine what sections of the building can be improved to enable the building to become more energy efficient.

5.2 Transmission Heat Losses

Transmission heat losses can occur by conduction, convection, and radiation [3,4]. This is a constant process during the heating season and is simply the flow of heat from inside the building to the outside due to the temperature being hotter indoors than outdoors. Heat always flows from a hot body to a cold body or in this case from the warm indoors to the cold outdoors. During the cooling season the process is reversed and heat transfer takes place from outside the building to the inside. Therefore, if the amount of heat lost in the winter can be reduced, the amount of heat gained in the summer will also be reduced.

The basic equation for determining transmission heat losses is:

$$q = (U) (A) (TD) \quad (5.1)$$

where:

q is the heat loss thru the building component, BTU/hr.

U is the heat transfer coefficient, BTU/hr/ft²/TD.

A is the area of building component, ft².

TD is the temperature difference between the two sides of the building component, degrees F.

The heat transfer coefficient U is calculated for each building component separately. Each typical wall, floor, and roof section along with each typical window and door will have its own value of U . The value of U is determined from the materials' resistance values.

Resistance R is a materials ability to resist the flow of heat and is directly proportional to a materials insulating value. A materials insulating value increases as its R value increases in magnitude. Resistance can be determined from values of conductivity and conductance.

Conductivity k is defined as a materials ability to conduct heat in BTU/hr per square foot of area per inch of thickness per degree difference in temperature between the two sides of the material perpendicular to the heat flow.

Conductance C is a materials ability to transfer heat in BTU/hr per square foot of area per degree difference in temperature between the two sides of the material. Whereas k is in terms of per inch thickness, values of C are for the thickness of the material stated.

In terms of conductivity and conductance R is equal to:

$$R = \frac{x}{K} \quad (5.2)$$

where:

R is the resistance of the material.

x is the thickness of the material, inches.

K is the conductivity coefficient, BTU/hr/ft²/in./TD.

$$R = \frac{1}{C} \quad (5.3)$$

where:

R is the resistance of the material.

C is the conductance coefficient, BTU/hr/ft²/TD.

Table 5.1* list values of conductivity, conductance, and resistance for common building materials. In order to determine the U coefficient for a building component each material used to construct the component must first be

* With permission of the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA 30329.

defined and then located in Table 5.1. This table does not contain all of the building materials used and it may be necessary to consult other references.

Air has insulating properties that must be considered when calculating U values for a building component. At the surface of a building component, a thin layer of air exists that adds to the insulating value of the other materials. Figure 5.1 shows where these thin layers of air exist. Table 5.2* list the values for the resistance of this thin layer of air.

Plane air spaces also add to the resistive values of a building component. A plane air space is of uniform thickness bounded by plane, smooth, parallel surfaces and are usually located in wall and ceiling cavities, see Figure 5.2. The amount of resistive value that a plane air space can add to a building component depends upon the position of the air space, the direction of the heat flow, the mean air temperature inside the air space, the difference in the temperature between the inside and outside of the air space, the thickness of the air space, and the effective emittance value of the air space. Table 5.3* lists the resistance values for plane air spaces.

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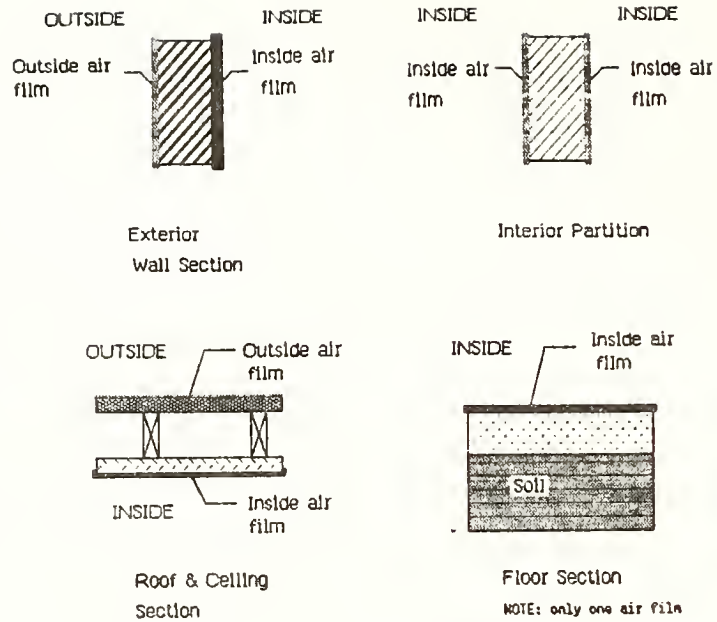


Figure 5.1 Location of Thin Air Films

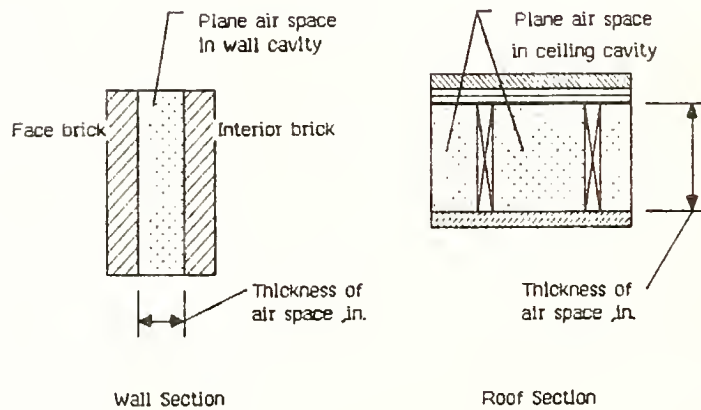


Figure 5.2 Location of Plane Air Spaces

Table 5.1 Thermal Properties of Typical Building and Insulating Materials - (Design Values)

Conductivity and conductance are expressed in Btu per (hour) (square foot) (degree Fahrenheit temperature difference). Conductivities (*k*) are per inch thickness, and conductances (*C*) are for thickness or construction stated, not per inch thickness. All values are for a mean temperature of 75 F, except as noted by an asterisk (*) which have been reported at 45 F.

Description	Density (lb/ft ³)	Conduc- tivity (k)	Conduc- tance (C)	Resistance ^a (R)		Specific Heat, Btu/(lb) (deg F)	Wt lb ft ³	Heat Capacity	
				Per inch thickness (1/k)	For thick- ness listed (1/C)			Btu ft ² · F	Btu ft ² · F
BUILDING BOARD^c									
Boards, Panels, Subflooring, Sheathing									
Woodboard Panel Products									
Asbestos-cement board	120	4.0	—	0.25	—	0.24	1.25	—	28.8
Asbestos-cement board, .0125 in.	120	—	33.00	—	0.03	—	2.50	0.30	28.8
Asbestos-cement board, .025 in.	120	—	16.50	—	0.06	—	1.56	0.41	28.8
Gypsum or plaster board, .0375 in.	50	—	3.10	—	0.32	0.26	2.08	0.54	13.0
Gypsum or plaster board, .05 in.	50	—	2.22	—	0.45	—	2.60	0.68	13.0
Gypsum or plaster board, .0625 in.	50	—	1.78	—	0.56	—	—	—	9.86
Plywood (Douglas Fir), .025 in.	34	0.80	—	1.25	—	0.29	0.71	0.21	9.86
Plywood (Douglas Fir), .0375 in.	34	—	3.20	—	0.31	—	1.06	0.31	9.86
Plywood (Douglas Fir), .05 in.	34	—	2.13	—	0.47	—	1.42	0.41	9.86
Plywood (Douglas Fir), .0625 in.	34	—	1.60	—	0.62	—	1.77	0.51	9.86
Plywood (Douglas Fir), .075 in.	34	—	1.29	—	0.77	—	—	—	9.86
Plywood or wood panels, .075 in.	34	—	1.07	—	0.93	0.29	2.13	0.62	9.86
Vegetable Fiber Board									
Sheathing, regular density, .05 in.	18	—	0.76	—	1.32	0.31	0.75	0.23	5.58
Sheathing, regular density, .078125 in.	18	—	0.49	—	2.06	—	1.17	0.36	5.58
Sheathing intermediate density, .05 in.	22	—	0.82	—	1.22	0.31	0.92	0.28	6.82
Nail-base sheathing, .05 in.	25	—	0.88	—	1.14	0.31	1.04	0.32	7.75
Shingle backer, .0375 in.	18	—	1.06	—	0.94	0.31	0.56	0.17	5.58
Shingle backer, .03125 in.	18	—	1.28	—	0.78	—	0.47	0.15	5.58
Sound deadening board, .05 in.	15	—	0.74	—	1.35	0.30	0.62	0.19	4.50
Tile and lay-in panels, plain or acoustic, .05 in.	18	0.40	—	2.50	—	0.14	—	—	2.52
Tile and lay-in panels, plain or acoustic, .075 in.	18	—	0.80	—	1.25	—	0.75	0.11	2.52
Tile and lay-in panels, plain or acoustic, .1 in.	18	—	0.53	—	1.89	—	1.13	0.16	2.52
Laminated paperboard, .05 in.	30	0.50	—	2.00	—	0.33	—	—	9.90
Homogeneous board from repulped paper, .05 in.	30	0.50	—	2.00	—	0.28	—	—	8.40
Hardboard									
Medium density, .05 in.	50	0.73	—	1.37	—	0.31	—	—	17.60
High density, service temp. service underlay, .05 in.	55	0.82	—	1.22	—	0.32	—	—	17.60
High density, std. tempered, .05 in.	63	1.00	—	1.00	—	0.32	—	—	20.16
Particleboard									
Low density, .05 in.	37	0.54	—	1.85	—	0.31	—	—	11.47
Medium density, .05 in.	50	0.94	—	1.06	—	0.31	—	—	15.50
High density, .05 in.	62.5	1.18	—	0.85	—	0.31	—	—	19.38
Underlayment, .0625 in.	40	—	1.22	—	0.82	0.29	2.08	0.6	11.60
Wood subfloor, .075 in.	—	—	1.06	—	0.94	0.33	2.00	0.6	9.60
BUILDING MEMBRANE									
Vapor—permeable felt, .05 in.	—	—	16.70	—	0.06	—	—	—	—
Vapor—seal, 2 layers of mopped 15-lb felt, .05 in.	—	—	8.35	—	0.12	—	—	—	—
Vapor—seal, plastic film, .05 in.	—	—	—	—	Negl.	—	—	—	—
FINISH FLOORING MATERIALS									
Carpet and fibrous pad, .05 in.	—	—	0.48	—	2.08	0.34	—	—	—
Carpet and rubber pad, .05 in.	—	—	0.81	—	1.23	0.33	—	—	—
Cork tile, .0125 in.	—	—	3.60	—	0.28	0.48	—	—	—
Terrazzo, 1 in.	—	—	12.50	—	0.08	0.19	11.7	2.22	26.60
Tile—asphalt, linoleum, vinyl, rubber, vinyl asbestos, ceramic, .075 in.	—	—	20.00	—	0.05	0.30	—	—	—
Wood, hardwood finish, .075 in.	—	—	1.47	—	0.68	0.19	2.81	0.84	13.50
INSULATING MATERIALS									
BLANKET AND BATT									
Mineral Fiber, fibrous form processed from rock, slag, or glass	—	—	—	—	—	—	—	—	—
approx. 2-2.75 in.	0.3-2.0	—	0.143	—	7 ^a	0.17-0.23	12-40	02-09	0.1-0.46
approx. 3-3.5 in.	0.3-2.0	—	0.091	—	11 ^a	—	16-54	03-12	0.1-0.46
approx. 3.50-6.5 in.	0.3-2.0	—	0.053	—	19 ^a	—	30-98	05-23	0.1-0.46
approx. 6-7 in.	0.3-2.0	—	0.045	—	22 ^a	—	30-110	05-25	0.1-0.46
approx. 8.5 in.	0.3-2.0	—	0.033	—	30 ^a	—	40-142	07-32	0.1-0.46
BOARD AND SLABS									
Cellular glass, .05 in.	8.5	0.38	—	2.63	—	0.24	—	—	2.64
Glass fiber, organic bonded, .05 in.	4-9	0.25	—	4.00	—	0.23	—	—	9-21
Expanded rubber (rigid), .05 in.	4.5	0.22	—	4.55	—	0.40	—	—	1.8
Expanded polystyrene extruded, .05 in.	1.8	0.25	—	4.00	—	0.24	—	—	0.52
Expanded polystyrene extruded, .05 in.	2.2	0.20	—	5.00	—	0.29	—	—	0.64
Expanded polystyrene extruded, .05 in.	3.5	0.19	—	5.26	—	—	—	—	1.02
Expanded polystyrene, molded beads, .05 in.	1.0	0.28	—	3.57	—	0.29	—	—	0.29
Expanded polyurethane ^f (R-11 exp.), .05 in.	1.5	0.16	—	6.25	—	0.38	—	—	0.57
a. (Thickness 1 in. or greater)	2.5	—	—	—	—	—	—	—	—

Table 5.1 Continued

Description	Density (lb/ft ³)	Conduc- tivity (k)	Conduc- tance (C)	Resistance ^a (R)		Specific Heat, Btu/(lb °F)	Wt lb ft ³	Heat Capacity	
				Per inch thickness (1/k)	For thick- ness listed (1/C)			Btu ft ³ · °F	Btu ft ³ · °F
Mineral fiber with resin binder	15	0.29	—	3.45	—	0.17	—	9.15	—
Mineral fiberboard, wet felted	—	—	—	—	—	—	—	—	—
Core or roof insulation	16-17	0.34	—	2.94	—	—	—	2.2-2.4	—
Acoustical tile	18	0.35	—	2.86	—	0.19	—	3.42	—
Acoustical tile	21	0.37	—	2.70	—	—	—	2.94	—
Mineral fiberboard, wet molded	—	—	—	—	—	—	—	—	—
Acoustical tile ^a	23	0.42	—	2.38	—	0.14	—	3.22	—
Wood or cane fiberboard	—	—	—	—	—	—	—	—	—
Acoustical tile ^a , 0.5 in.	—	—	0.80	—	1.25	* 0.31	—	—	—
Acoustical tile ^a , 0.75 in.	—	—	0.53	—	1.89	—	—	—	—
Interior finish (plank, tile)	15	0.35	—	2.86	—	0.32	—	4.80	—
Wood shredded (cemented in preformed slabs)	22	0.60	—	1.67	—	0.31	—	—	6.82
LOOSE FILL									
Cellulosic insulation (milled paper or wood pulp)	2.3-3.2	0.27-0.32	—	3.13-3.70	—	0.33	—	—	—
Sawdust or shavings	8.0-15.0	0.45	—	2.22	—	0.33	—	—	—
Wood fiber, softwoods	2.0-3.5	0.30	—	3.33	—	0.33	—	—	—
Perlite, expanded	5.0-8.0	0.37	—	2.70	—	0.26	—	—	—
Mineral fiber (rock, slag or glass)	—	—	—	—	—	—	—	—	—
approx. ^a 3.75-5 in.	0.6-2.0	—	—	—	11	0.17	0.2-0.71	0.04-0.12	0.1
approx. ^a 6.5-8.75 in.	0.6-2.0	—	—	—	19	—	51-1.27	0.06-0.22	0.1-0.34
approx. ^a 7.5-10 in.	0.6-2.0	—	—	—	22	—	45-1.46	0.07-0.25	0.1-0.34
approx. ^a 10.25-13.75 in.	0.6-2.0	—	—	—	30	—	60-2.02	0.1-0.34	0.1-0.34
Vermiculite, exfoliated	7.0-8.2	0.47	—	2.13	—	3.20	—	—	—
4.0-6.0	0.44	—	—	2.27	—	—	—	0.8-1.2	—
ROOF INSULATION^b									
Preformed, for use above deck	—	—	—	—	—	—	—	—	—
Different roof insulations are available in different thicknesses to provide the design C values listed. ^b Consult individual manufacturers for actual thickness of their material	—	—	0.72 to 0.12	—	1.39 to 8.33	—	—	—	—
MASONRY MATERIALS									
CONCRETES									
Cement mortar	116	5.0	—	0.20	—	—	—	—	23.2
Gypsum-fiber concrete 87.5% gypsum, 12.5% wood chips	51	1.66	—	0.60	—	0.21	—	—	10.71
Lightweight aggregates including ex- panded shale, clay or slate; expanded slags; cinders; pumice; vermiculite; also cellular concretes	120	5.2	—	0.19	—	—	—	—	24.0
100	3.6	—	—	0.28	—	—	—	—	20.0
80	2.5	—	—	0.40	—	—	—	—	16.0
40	1.7	—	—	0.59	—	—	—	—	12.0
20	1.15	—	—	0.86	—	—	—	—	8.0
30	0.90	—	—	1.11	—	—	—	—	6.0
20	0.70	—	—	1.43	—	—	—	—	4.0
Perlite, expanded	40	0.93	—	1.08	—	—	—	—	12.8
30	0.71	—	—	1.41	—	—	—	—	9.6
20	0.50	—	—	2.00	—	0.32	—	—	6.4
Sand and gravel or stone aggregate (oven dried)	140	9.0	—	0.11	—	0.22	—	—	30.8
Sand and gravel or stone aggregate (not dried)	140	12.0	—	0.08	—	—	—	—	28.0
Stucco	116	5.0	—	0.20	—	—	—	—	23.2
MASONRY UNITS									
Brick, common ¹	120	5.0	—	0.20	—	0.19	—	—	22.8
Brick, face ¹	130	9.0	—	0.11	—	—	—	—	24.7
Clay tile, hollow:	—	—	—	—	—	—	—	—	—
1 cell deep	3 in.	—	1.25	—	0.80	0.21	15.0	3.2	12.6
1 cell deep	4 in.	—	0.90	—	1.11	—	16.0	3.4	10.1
2 cells deep	6 in.	—	0.66	—	1.52	—	25.0	5.25	10.5
2 cells deep	8 in.	—	0.54	—	1.88	—	30.0	6.3	9.5
2 cells deep	10 in.	—	0.45	—	2.22	—	35.0	7.4	8.8
3 cells deep	12 in.	—	0.40	—	2.50	—	40.0	8.4	8.4
Concrete blocks, three oval core:	—	—	—	—	—	—	—	—	—
Sand and gravel aggregate	4 in.	—	1.40	—	0.71	0.22	23.0	5.1	15.2
8 in.	—	—	0.90	—	1.11	—	43.0	9.4	14.1
12 in.	—	—	0.78	—	1.28	—	63.0	13.9	13.9
Cinder aggregate	3 in.	—	1.16	—	0.86	0.21	17.0	3.6	14.3
4 in.	—	—	0.90	—	1.11	—	20.0	4.2	12.6
8 in.	—	—	0.58	—	1.72	—	37.0	7.9	11.8
12 in.	—	—	0.53	—	1.89	—	53.0	11.1	11.1
Lightweight aggregate	3 in.	—	0.79	—	1.27	0.21	15.0	2.6	12.6
(expanded shale, clay, slate	4 in.	—	0.67	—	1.50	—	17.0	3.6	10.9
or slag; pumice)	8 in.	—	0.50	—	2.00	—	32.0	6.7	10.1
12 in.	—	—	0.44	—	2.27	—	43.0	9.0	9.0
Concrete blocks, rectangular core. ²	—	—	—	—	—	—	—	—	—
Sand and gravel aggregate	—	—	—	—	—	—	—	—	—
2 core, 8 in. 36 lb. ^{1/2}	—	—	0.96	—	1.04	0.22	43.1	9.5	14.2
Same with filled cores ²	—	—	0.52	—	1.93	0.22	—	—	—

Table 5.1 Continued

Description	Customary Units								
	Density (lb/ft ³)	Conduc- tivity (k)	Conduc- tance (C)	Resistance ^a (R)		Specific Heat, Btu/(lb deg F)	Wt lb ft ³	Heat Capacity	
				Per inch thickness (1/k)	For thick- ness listed (1/C)			Btu ft ² · F	Btu ft ² · F
Lightweight aggregate (expanded shale, clay, slate or slag, pumice):									
3 core, 6 in. 19 lb. ^{1,2}	—	—	0.61	—	1.65	0.21	22.8	4.6	9.6
Same with filled cores ^{1a}	—	—	0.33	—	2.99	—	—	—	—
2 core, 8 in. 24 lb. ^{1,2}	—	—	0.46	—	2.18	—	28.8	6.0	9.1
Same with filled cores ^{1a}	—	—	0.20	—	5.03	—	—	—	—
3 core, 12 in. 38 lb. ^{1,2}	—	—	0.40	—	2.48	—	45.6	9.6	9.6
Same with filled cores ^{1a}	—	—	0.17	—	5.82	—	—	—	—
Stone, lime or sand	—	12.50	—	0.08	—	0.19	—	—	28.5
Gypsum partition tile:									
3 × 12 × 30 in. solid	—	—	0.79	—	1.26	0.19	11.0	2.1	8.6
3 × 12 × 30 in. 4-cell	—	—	0.74	—	1.35	—	9.0	1.7	6.7
4 × 12 × 30 in. 3-cell	—	—	0.60	—	1.67	—	13.0	2.5	7.2
PLASTERING MATERIALS									
Cement plaster, sand aggregate	116	5.0	—	0.20	—	0.20	—	—	23.2
Sand aggregate	—	—	13.3	—	0.08	0.20	1.63	0.72	23.2
Sand aggregate	—	—	6.66	—	0.15	0.20	7.25	1.45	23.2
Gypsum plaster	—	—	—	—	—	—	—	—	—
Lightweight aggregate	45	—	3.12	—	0.32	—	1.88	0.38	9.0
Lightweight aggregate	45	—	2.67	—	0.39	—	2.14	0.47	9.0
Lightweight agg. on metal lath	—	—	2.13	—	0.47	—	—	0.57	—
Perlite aggregate	45	1.5	—	0.67	—	0.32	—	—	14.4
Sand aggregate	105	5.6	—	0.18	—	0.20	—	—	21.0
Sand aggregate	105	—	11.10	—	0.09	—	4.38	0.88	21.0
Sand aggregate	105	—	9.10	—	0.11	—	5.47	1.09	21.0
Sand aggregate on metal lath	—	—	7.70	—	0.13	—	—	1.32	—
Vermiculite aggregate	45	1.7	—	0.59	—	—	—	—	9.0
ROOFING									
Asbestos-cement shingles	120	—	4.76	—	0.21	0.24	—	—	38.8
Asphalt roll roofing	70	—	6.50	—	0.15	0.36	—	—	25.2
Asphalt shingles	70	—	2.27	—	0.44	0.30	—	—	25.2
Built-up roofing	—	—	3.00	—	0.33	0.35	2.19	0.73	24.5
Slate	—	—	20.00	—	0.05	0.30	—	—	—
Wood shingles, plain and plastic film faced	—	—	1.06	—	0.94	0.31	—	—	—
SIDING MATERIALS (ON FLAT SURFACE)									
Shingles									
Asbestos-cement	120	—	4.75	—	0.21	—	—	—	28.8
Wood, 16 in., 7.5 exposure	—	—	1.15	—	0.87	0.31	—	—	—
Wood, double, 16 in., 12 in. exposure	—	—	0.84	—	1.19	0.28	—	—	—
Wood, plus insul. backer board, 0.3125 in.	—	—	0.71	—	1.40	0.31	—	—	—
Siding									
Asbestos-cement, 0.25 in., lapped	—	—	4.76	—	0.21	0.24	—	—	29.5
Asphalt roll siding	—	—	6.50	—	0.15	0.35	—	—	24.5
Asphalt insulating siding (0.5 in. bed.)	—	—	0.69	—	1.46	0.35	—	—	—
Wood, drop, 1 × 8 in., lapped	—	—	1.27	—	0.79	0.28	—	—	—
Wood, bevel, 0.5 × 8 in., lapped	—	—	1.23	—	0.81	0.28	—	—	—
Wood, bevel, 0.75 × 10 in., lapped	—	—	0.95	—	1.05	0.28	—	—	—
Wood, plywood, 0.375 in., lapped	—	—	1.59	—	0.59	0.29	—	—	—
Wood, medium density siding, 0.4375 in.	40	1.49	—	0.67	—	0.28	—	—	11.5
Aluminum or Steel³, over sheathing									
Hollow-backed	—	—	1.61	—	0.61	0.29	—	—	—
Insulating-board backed nominal	—	—	0.55	—	1.82	0.32	—	—	—
0.375 in.	—	—	—	—	—	—	—	—	—
Insulating-board backed nominal	—	—	0.34	—	2.96	—	—	—	—
0.375 in., foil backed	—	—	10.00	—	0.10	0.20	—	—	—
Architectural glass	—	—	—	—	—	—	—	—	—
WOODS									
Maple, oak, and similar hardwoods	45	1.10	—	0.91	—	0.30	—	—	13.5
Fir, pine, and similar softwoods	32	0.80	—	1.25	—	0.33	—	—	10.6
Fir, pine, and similar softwoods	32	—	1.06	—	0.94	0.33	2.0	0.66	10.6
—	—	—	0.53	—	1.89	—	4.0	1.32	10.6
—	—	—	0.32	—	3.12	—	6.7	2.20	10.6
—	—	—	0.23	—	4.35	—	9.3	3.08	10.6

^a Representative values for dry materials were selected by ASHRAE TC 4.4, Insulation and Moisture Barriers. They are intended as design (not specification) values for materials in normal use. For properties of a particular product, use the value supplied by the manufacturer or by unbiased tests.

^b Resistance values are the reciprocals of C before rounding off C to two decimal places.

^c Also see Insulating Materials, Board.

^d Does not include paper backing and facing, if any. Where insulation forms a boundary (effective or otherwise) of an air space, see Tables 3.3 and 3.4 for the insulating value of air space for the appropriate effective emittance and temperature conditions of the space.

^e Conductivity varies with fiber diameter. Insulation is produced by different densities, therefore there is a wide variation in thickness for the same R-value among manufacturers. No effort should be made to relate any specific R-value to any specific thickness.

^f Values are for aged board stock. For change in conductivity with age of expanded urethane, see Chapter 19, Factors Affecting Thermal Conductivity 1977 Fundamentals Volume.

^g Insulating values of acoustical tile vary, depending on density of the board and on type, size, and depth of perforations.

^h The U. S. Department of Commerce, *Simplified Practice Recommendation for Thermal Conductivity Factors for Prefabricated Above Deck Roof Insulation*, No. B-257-55, recognizes the specification of roof insulation on the basis of the C-values shown. Roof insulation is made in thicknesses to meet these values.

ⁱ Face brick and common brick do not always have these specific densities. When density is different from that shown, there will be a change in thermal conductivity.

^j Data on rectangular core concrete blocks differs from the above data on oval core blocks, due to core configuration, different mean temperatures, and possibly differences in unit weights. Weight data on the oval core blocks tested are not available.

^k Weight of units approximately 7.625 in. high and 15.75 in. long. These weights are given as a means of describing the blocks tested, but conductance values are all for 1 ft² of area.

^l Vermiculite, perlite, or mineral wool insulation. Where insulation is used, vapor barriers or other precautions must be considered to keep insulation dry.

^m Values for metal siding applied over flat surfaces vary widely, depending on amount of ventilation of air space beneath the siding; whether air space is reflective or nonreflective; and on thickness, type, and application of insulating backing-board used. Values given are averages for use as design guides, and were obtained from several guarded hotbox tests (ASTM C236) or calibrated hotbox (BSS 77) on hollow-backed types and types made using backing boards of wood fiber, foamed plastic, and glass fiber. Departures of 50% or more from the values given may occur.

Table 5.2 Surface Conductances and Resistances for Air

All conductance values expressed in $\text{Btu} \cdot (\text{hr} \cdot \text{ft}^2 \cdot \text{F})^{-1}$
 A surface cannot take credit for both an air space resistance value and a surface resistance value
 No credit for an air space value can be taken for any surface facing an air space of less than 0.5 in

SECTION A. Surface Conductances and Resistances ^{a,b}							SECTION B. Reflectance and Emittance Values of Various Surfaces and Effective Emittances of Air Spaces					
Position of Surface	Direction of Heat Flow	Surface Emittance						Surface	Reflectance In Percent	Average Emittance ^c	Effective Emittance <i>E</i> of Air Space	
		Non-reflective $\epsilon = 0.90$		Reflective $\epsilon = 0.20$		Reflective $\epsilon = 0.05$					One surface emittance ϵ_1 the other 0.90	Both surfaces emittances ϵ_1 and ϵ_2
		h_1	<i>R</i>	h_1	<i>R</i>	h_1	<i>R</i>					
STILL AIR												
Horizontal	Upward	1.63	0.61	0.91	1.10	0.76	1.32	Aluminum foil, bright	92 to 97	0.05	0.05	0.03
Sloping—45 deg	Upward	1.60	0.62	0.88	1.14	0.73	1.37	Aluminum sheet	80 to 95	0.12	0.12	0.06
Vertical	Horizontal	1.46	0.68	0.74	1.35	0.59	1.70	Aluminum coated paper, polished	75 to 84	0.20	0.20	0.11
Sloping—45 deg	Downward	1.32	0.76	0.60	1.67	0.45	2.22	Steel, galvanized, bright . . .	70 to 80	0.25	0.24	0.15
Horizontal	Downward	1.08	0.92	0.37	2.70	0.22	4.55	Aluminum paint	30 to 70	0.50	0.47	0.35
MOVING AIR												
(Any Position)		h_a	<i>R</i>	h_a	<i>R</i>	h_a	<i>R</i>	Building materials: wood, paper, masonry, nonmetallic paints	5 to 15	0.90	0.82	0.82
15-mph Wind (for winter)	Any	6.00	0.17					Regular glass	5 to 15	0.84	0.77	0.72
7.5-mph Wind (for summer)	Any	4.00	0.25									

For ventilated attics or spaces above ceilings under summer conditions (heat flow down) see Table 3.5.

^aConductances are for surfaces of the stated emittance facing virtual blackbody surroundings at the same temperature as the ambient air. Values are based on a surface-air temperature difference of 10 deg F and for surface temperature of 70 F.

Table 5.3 Thermal Resistances of Plane Air Spaces

All resistance values expressed in (hour) (square foot) (degree Fahrenheit temperature difference) per Btu. Values apply only to air spaces of uniform thickness bounded by plane, smooth, parallel surfaces with no leakage of air to or from the space. Thermal resistance values for multiple air spaces must be based on careful estimates of mean temperature differences for each air space.

Position of Air Space	Direction of Heat Flow	Air Space		0.5 in. Air Space					0.75 in. Air Space ^c				
		Mean Temp. ^a (F)	Temp Diff. ^a (deg F)	Value of $E^{a,b}$					Value of $E^{a,b}$				
				0.01	0.05	0.2	0.5	0.81	0.01	0.05	0.2	0.5	0.81
Horiz.	Up	90	10	2.13	2.03	1.51	0.99	0.73	2.34	2.22	1.61	1.04	0.75
		30	30	1.62	1.37	1.29	0.96	0.75	1.71	1.66	1.35	0.99	0.77
		50	10	2.13	2.05	1.60	1.11	0.84	2.30	2.21	1.70	1.16	0.87
		0	20	1.73	1.70	1.45	1.12	0.91	1.83	1.79	1.52	1.16	0.93
		0	10	2.10	2.04	1.70	1.27	1.00	2.23	2.16	1.78	1.31	1.02
		-30	20	1.69	1.66	1.49	1.23	1.04	1.77	1.74	1.55	1.27	1.07
45° Slope	Up	-50	10	2.04	2.00	1.75	1.40	1.16	2.16	2.11	1.84	1.46	1.20
		90	10	2.44	2.31	1.65	1.06	0.76	2.96	2.78	1.88	1.15	0.81
		30	30	2.06	1.98	1.56	1.10	0.83	1.99	1.92	1.52	1.08	0.82
		50	10	2.55	2.44	1.83	1.22	0.90	2.90	2.75	2.00	1.29	0.94
		0	20	2.20	2.14	1.76	1.30	1.02	2.13	2.07	1.72	1.28	1.00
		0	10	2.63	2.54	2.03	1.44	1.10	2.72	2.62	2.08	1.47	1.12
Vertical	Horiz.	-30	20	2.08	2.04	1.78	1.42	1.17	2.05	2.01	1.76	1.41	1.16
		-50	10	2.62	2.56	2.17	1.66	1.31	2.53	2.47	2.10	1.62	1.30
		90	10	2.47	2.34	1.67	1.06	0.77	3.50	3.24	2.08	1.22	0.84
		30	30	2.57	2.46	1.84	1.23	0.90	2.91	2.77	2.01	1.30	0.94
		50	10	2.66	2.54	1.88	1.24	0.91	3.70	3.46	2.35	1.43	1.01
		0	20	2.82	2.72	2.14	1.50	1.13	3.14	3.02	2.32	1.56	1.18
45° Slope	Down	0	10	2.93	2.82	2.20	1.53	1.15	3.77	3.59	2.64	1.73	1.26
		-30	20	2.90	2.82	2.35	1.76	1.39	2.90	2.83	2.36	1.77	1.39
		-50	10	3.20	3.10	2.54	1.87	1.46	3.72	3.60	2.87	2.04	1.56
		90	10	2.48	2.34	1.67	1.06	0.77	3.53	3.27	2.10	1.22	0.84
		30	30	2.64	2.52	1.87	1.24	0.91	3.43	3.23	2.24	1.39	0.99
		50	10	2.67	2.55	1.89	1.25	0.92	3.81	3.57	2.40	1.45	1.02
Horiz.	Down	0	20	2.91	2.80	2.19	1.52	1.15	3.73	3.57	2.63	1.72	1.26
		0	10	2.94	2.83	2.21	1.53	1.15	4.12	3.91	2.81	1.80	1.30
		-30	20	3.16	3.07	2.52	1.86	1.45	3.78	3.65	2.90	2.05	1.57
		-50	10	3.26	3.16	2.58	1.89	1.47	4.35	4.18	3.22	2.21	1.66
		90	10	2.48	2.34	1.67	1.06	0.77	3.53	3.29	2.10	1.22	0.83
		30	30	2.66	2.54	1.88	1.24	0.91	3.77	3.52	2.38	1.44	1.02

Table 5.3 Continued

Position of Air Space	Direction of Heat Flow	Air Space		1.9-in. Air Space ^d					3.5-in. Air Space ^d				
		Mass Temp., ° (F)	Temp Diff., (deg F)	Value of $E^{b,c}$					Value of $E^{b,c}$				
				0.03	0.05	0.2	0.5	0.82	0.03	0.05	0.2	0.5	0.82
Horiz.	Up	90	10	2.55	2.41	1.71	1.08	0.77	2.84	2.66	1.83	1.13	0.80
		50	30	1.87	1.81	1.45	1.04	0.80	2.09	2.01	1.58	1.10	0.84
		50	10	2.50	2.40	1.81	1.21	0.89	2.80	2.66	1.95	1.28	0.93
		0	20	2.01	1.95	1.63	1.23	0.97	2.25	2.18	1.79	1.32	1.03
		0	10	2.43	2.35	1.90	1.38	1.06	2.71	2.62	2.07	1.47	1.12
		-50	20	1.94	1.91	1.68	1.36	1.13	2.19	2.14	1.86	1.47	1.20
45° Slope	Up	-50	10	2.37	2.31	1.99	1.55	1.26	2.65	2.58	2.18	1.67	1.33
		90	10	2.92	2.73	1.86	1.14	0.80	3.18	2.96	1.97	1.18	0.82
		50	30	2.14	2.06	1.61	1.12	0.84	2.26	2.17	1.67	1.15	0.86
		50	10	2.88	2.74	1.99	1.29	0.94	3.12	2.95	2.10	1.34	0.96
		0	20	2.30	2.23	1.82	1.34	1.04	2.42	2.35	1.90	1.38	1.06
		0	10	2.79	2.69	2.12	1.49	1.13	2.98	2.87	2.23	1.54	1.16
Vertical	Horiz.	-50	20	2.22	2.17	1.88	1.49	1.21	2.34	2.29	1.97	1.54	1.23
		-50	10	2.71	2.64	2.23	1.69	1.35	2.87	2.79	2.23	1.75	1.39
		90	10	3.99	3.66	2.25	1.27	0.87	3.69	3.40	2.15	1.24	0.85
		50	30	2.58	2.46	1.84	1.23	0.90	2.67	2.55	1.89	1.25	0.91
		50	10	3.79	3.55	2.39	1.45	1.02	3.63	3.40	2.32	1.42	1.01
		0	20	2.76	2.66	2.10	1.48	1.12	2.88	2.78	2.17	1.51	1.14
45° Slope	Down	0	10	3.51	3.35	2.51	1.87	1.23	3.49	3.33	2.50	1.67	1.23
		-50	20	2.64	2.58	2.18	1.66	1.33	2.82	2.75	2.30	1.73	1.37
		-50	10	3.31	3.21	2.62	1.91	1.48	3.40	3.30	2.67	1.94	1.50
		90	10	5.07	4.55	2.56	1.36	0.91	4.81	4.33	2.49	1.34	0.90
		50	30	3.58	3.36	2.31	1.42	1.00	3.51	3.30	2.49	1.40	1.00
		50	10	5.10	4.66	2.85	1.60	1.09	4.74	4.36	2.73	1.57	1.08
Horiz.	Down	0	20	3.85	3.66	2.68	1.74	1.27	3.81	3.63	2.66	1.74	1.27
		0	10	4.92	4.62	3.16	1.94	1.37	4.59	4.32	3.02	1.88	1.34
		-50	20	3.62	3.50	2.80	2.01	1.54	3.77	3.64	2.90	2.05	1.57
		-50	10	4.67	4.47	3.40	2.29	1.70	4.50	4.32	3.31	2.25	1.68
		90	10	6.09	5.35	2.79	1.43	0.94	10.07	8.19	3.41	1.37	1.00
		50	30	6.27	5.63	3.18	1.70	1.14	9.60	8.17	3.86	1.88	1.22
45° Slope	Up	50	10	6.61	5.90	3.27	1.73	1.15	11.13	9.27	4.09	1.93	1.24
		0	20	7.03	6.43	3.91	2.19	1.49	10.90	9.32	4.87	2.47	1.62
		0	10	7.31	6.66	4.00	2.22	1.51	11.97	10.32	5.08	2.52	1.64
		-50	20	7.73	7.20	4.77	2.85	1.99	11.64	10.49	6.02	3.25	2.18
		-50	10	8.09	7.52	4.91	2.89	2.01	12.98	11.58	6.36	3.34	2.22

^aInterpolation is permissible for other values of mean temperature, temperature differences, and effective emittance E . Interpolation and moderate extrapolation for air spaces greater than 3.5 in. are also permissible.

^bEffective emittance of the space E is given by $1/E = 1/e_1 + 1/e_2 - 1$, where e_1 and e_2 are the emittances of the surfaces of the air space (See section B of Table 3.1).

^cCredit for an air space resistance value cannot be taken more than once and only for the boundary conditions established.

^dResistances at horizontal spaces with heat flow downward are substantially independent of temperature difference.

Thermal resistance values were determined from the relation $R = 1/C$, where $C = h + Eh_c$, h is the conduction-convection coefficient, Eh_c is the radiation coefficient $\approx 0.00686 E [(460 + t_m)^3]$, and t_m is the mean temperature of the air space. For interpolation from Table 3.4 to air space thicknesses less than 0.5 in. (as in insulating window glass), assume $h_c = 0.795 (+0.0016)$ and compute R values from the above relations for an air space thickness of 0.2 in.

^eBased on National Bureau of Standards data presented in Housing Research Paper No. 32, Housing and Home Finance Agency 1954, U. S. Government Printing Office, Washington 20402.

After each resistance has been determined for the material and air, the total U coefficient for each building component can then be determined with the following equation:

$$U = \frac{1}{R_1 + R_2 + R_3 + \dots + R_n} \quad (5.4)$$

where:

U is the heat transfer coefficient, BTU/hr/ft²/TD.

R₁, R₂, and R₃ are the resistances of materials 1, 2 and 3.

R_n is the resistance of the nth material in the building component.

or

$$U = \frac{1}{R_T} \quad (5.5)$$

where:

R_T is the total resistance of the material in the building component.

The calculation procedures for transmission heat losses are explained for the major building components, shown in Figure 5.3, in section 5.6.

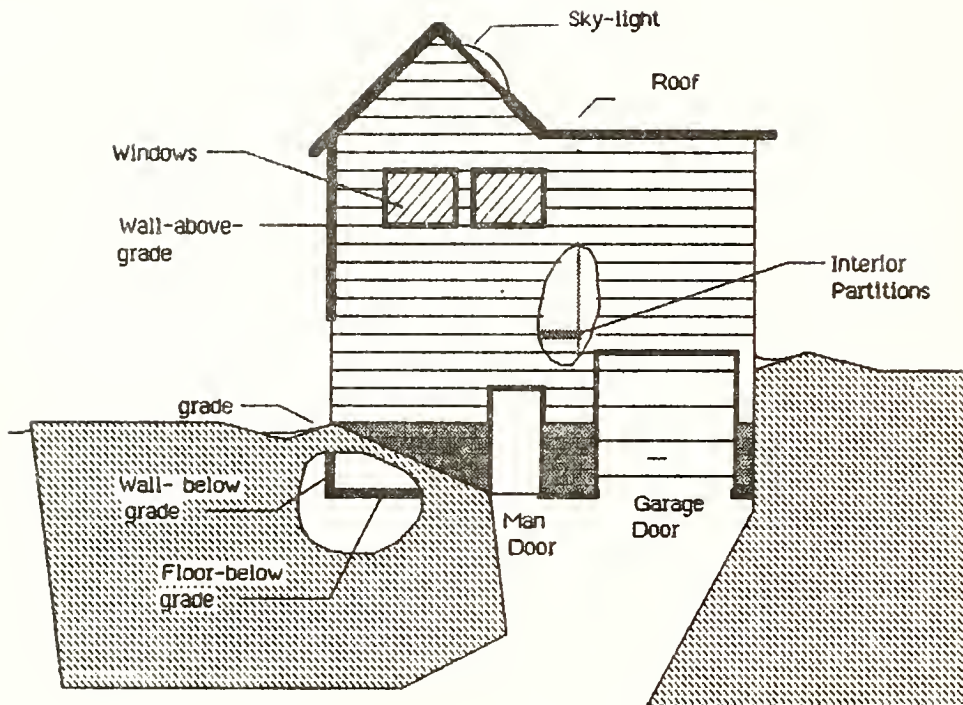


Figure 5.3 Major Building Components for Determining Heat Losses

5.3 Infiltration Heat Losses

Infiltration is the leakage of air into a building thru cracks in the building's facade, cracks around doors, cracks around windows, and opened doors and windows. Infiltration is often confused with ventilation. Ventilation is the process of bringing air into a building to provide fresh air for the occupants and to supply enough additional air for combustion processes. The difference between infiltration and ventilation is in the way the air enters into the building. Infiltration enters into the building in an uncontrolled manner and ventilation air enters into the building in a controlled manner. Ventilation air is usually brought into a building with fans, controlled dampers or vents. Ventilation is very important in providing a safe environment. On the other hand, infiltration is additional air that enters into building and the result is an increase in the amount of money that must be spent on utility bills due to an increased heating load. Therefore, one goal in the energy audit process is to determine where infiltration is occurring and reduce its quantity.

The major driving force that produces infiltration in a one to two story building is wind pressure. The major factors affecting wind pressure include average velocity, prevailing direction, seasonal and daily variation in velocity and direction, and local obstructions such as nearby

buildings, hills, trees, and shrubbery [3].

To analyze a building for infiltration, first determine from what direction the wind is coming from. The two situations in which wind applies pressure to a building is through a broadside or quartering wind. Figure 5.4 shows the two wind pressure situations. The broadside wind applies pressure to only one side of the building while the quartering wind applies pressure to two sides of the building. If the building being audited has a broadside wind, then only the infiltration through the windows, doors, and walls on the side of the building that the broadside wind is blowing on will be analyzed. In the quartering wind situation, only the two walls that the quartering wind is blowing on will be analyzed.

The best way to determine the prevailing wind direction is to ask people who work in the building. Table 3.1 contains limited data on wind velocity.

When air enters into a building via infiltration the same amount of air must exit the building. This air is referred to as exfiltration, see Fig. 5.4, and is always equal in quantity to the infiltration air. By limiting the amount of air that exits the building, the amount of infiltration is also reduced. Therefore, the energy auditor will still be concerned with all exterior walls when he/she begins to recommend actions to limit infiltration.

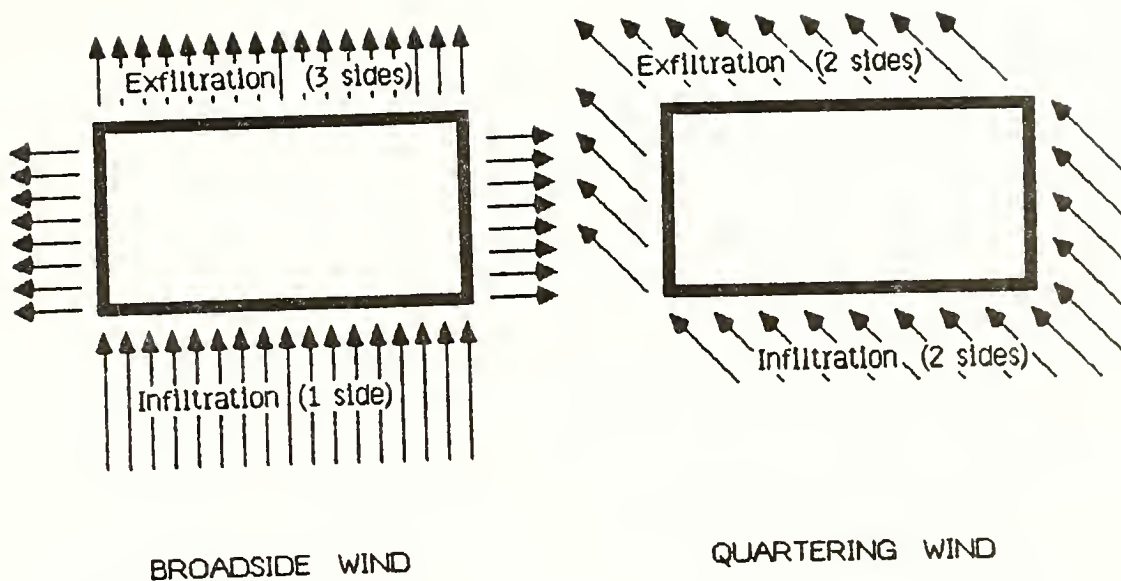


Figure 5.4 Infiltration Caused by Broadside and Quartering Wind.

Because of the many varying factors that effect wind pressure and the difficulties in determining magnitude and direction, infiltration is very hard to quantify. Calculation procedures will be presented to estimate how much of a building's heat loss is contributed by infiltration, but the important thing to remember when auditing a building is to understand what causes infiltration, where it occurs in a building, and what measures can be taken to limit the amount of infiltration.

The basic equation for determining infiltration heat loss is:

$$q = 1.08 \times TD \times cfm \quad (5.6)$$

where:

q is the heat loss due to infiltration in BTU/hr.

1.08 has units of BTU/hr/cfm/⁰F.

TD Inside-outside temperature difference in degrees F.

cfm is the infiltration in cubic feet per minute, cfm.

The difficult part in using equation 5.6 is in determining the cfm. The calculation procedures for infiltration heat losses through doors, windows, and walls are explained in section 5.7.

5.4 Required Material to Complete Heat Loss Calculations

* Completed BIF

* Copies of FORM 5.1 Transmission Coefficient (U) Calculation Form and FORM 5.2 Heat Loss Calculation Form, see Appendix A.

* Tables 5.1 to 5.12

* Pencil

* Calculator

5.5 Procedures to Complete Heat Loss Calculations

Form 5.1 and 5.2 are provided to enable the heat loss calculations to be done in a systematic manner. The following procedures explain the steps to take in using the forms followed by the procedures for determining the heat losses through the major building components.

5.5.1 Instructions for Form 5.1

STEP 1: Fill out the top portion of the form, see Figure 5.6, page 137.

STEP 2: Complete Section 1 of the form.

1. Sketch the cross section of the building component. Do this for each building component identified on the BIF.
2. Describe the material in the cross section in enough detail that it can be identified in the tables.
3. Indicate the thickness of the material in inches. This is especially important for materials that have their resistances given in terms of conductivity per inch.

STEP 3: Complete Section 2 of the form for each building component identified in Section 1.

1. Enter the path location where the coefficient of transmission is being calculated.

Section 2 has two columns for values of $1/K$, R , and U . This is required for building components with two heat transmission paths. As an example, a wall built from nominal 2 in. by 4 in. wood studs 16 in. on center, 3.5 inches batt insulation, and 0.5 in. gypsum wall board has two heat transmission paths. Figure 5.5 shows the location of the two heat transfer paths.

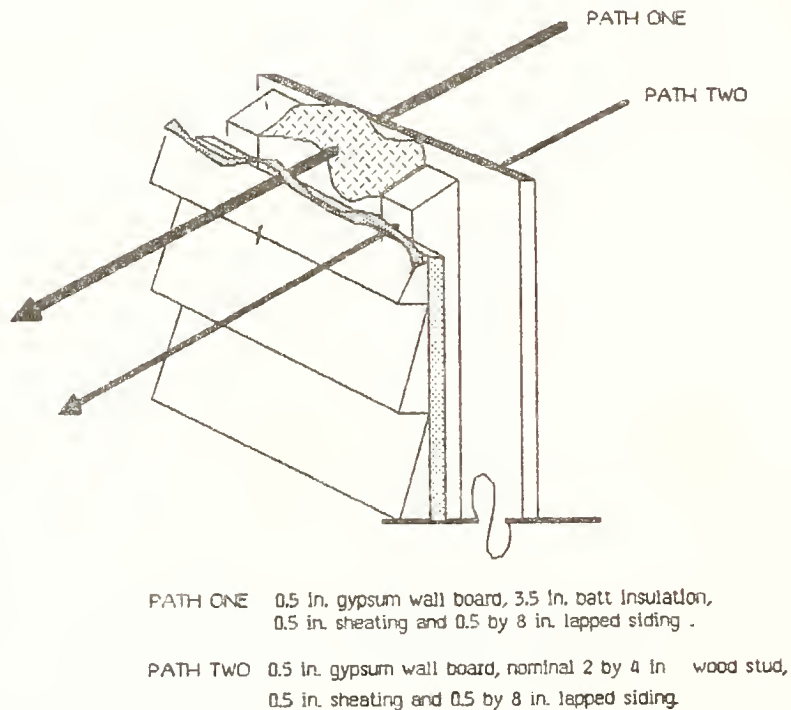


Figure 5.5 Exterior Wall Heat Transfer Paths

The combination of the material in path 1 has a different total value of resistance and coefficient of

transmissivity than path 2 due to the different combinations of material in the two paths. By weighting the transmissivity (U) with the percentage of construction for each path an average value of transmissivity can be calculated for the wall. The size and spacing of the studs in the wall or roof sections determines the percentages to be multiplied with the transmissivity to arrive at an average value.

An average U value for a wall or roof section is calculated using Eq. 5.7 as follows:

$$U_{avg} = (\% P1)(U_{P1}) + (\% P2)(U_{P2}) \quad (5.7)$$

U_{avg} - is the average U value for the wall or roof section.

$\% P1$ - is the construction percentage for path 1 from Table 5.4.

U_{P1} - is the calculated U value for path 1.

$\% P2$ - is the construction percentage for path 2 from Table 5.4.

U_{P2} - is the calculated U value for path 2.

Table 5.4 lists the percentages for the different framing sizes and spacings. This point will further be illustrated in the examples that follow.

Table 5.4 Construction Percentages For Walls and Roof Framing

Material	Spacing Inches	Percentage Between Framing	Percentage At Framing
1 by	12	94	06
	16	95	05
	24	97	03
	32	98	02
2 by	12	88	12
	16	90	10
	24	94	06
	32	95	05
3 by	12	79	21
	16	84	16
	24	90	10
	32	92	08
4 by	12	71	29
	16	78	22
	24	85	15
	32	89	11

STEP 3 CONTINUED

2. Using Table 5.1 enter the value of conductivity for the material described in section 1.
3. To determine the R value multiply the Thickness with the Conductivity.
4. Using Tables 5.1 to 5.3 enter the value of resistance for the remaining materials of section one.
5. For each building component sum the resistances to get a total resistance of the section.
6. Calculate the total U value where $U = 1/R$
7. For components with two paths, calculate an average U value using Eq. 5.7 and Table 5.4.

[illegible]

Figure 5.6 Form 5.1 Transmission (U) Calculation Sheet

5.5.2 Instructions for Form 5.2

STEP 1: Complete the top portion of the form, see Figure 5.7.

STEP 2: Complete section 1 Transmission Heat Losses

1. Enter a brief description of the building component
2. Enter the U Value calculated from Form 5.1
3. Enter the area of the building component in square feet
4. Calculate the temperature difference (TD) between the two sides of the building component.
5. Calculate the heat loss in BTU per hr for the building component by multiplying the U, Area and TD together.
6. Repeat steps 1 thru 5 for each building component
7. Sub-total the transmission heat losses for the entire building.

STEP 3: Complete Section 2 INFILTRATION

1. Enter the location of the infiltration and calculate the heat loss due to infiltration through each component.
2. Enter the amount of heat loss.
3. Sub-total the infiltration heat losses.
4. Total the transmission and infiltration heat losses.

Form 5.2 Heat Loss Calculation Form				
Building <u>STEP 1</u>	Heat Loss Calc. _____			
Location _____	Sheet No. _____			
Auditor _____	Date _____			
Chck'd By _____	Date _____			
Inside Temperature <u>(BIF)</u> °F		Outside Temperature <u>(Table 3.1)</u> °F		
SECTION 1 TRANSMISSION HEAT LOSSES		STEP 2		
BUILDING COMPONENT	U VALUE	AREA SQ. FT.	TD ° F	Q BTU/HR
1	2	3	4	5
6				
Sub-total				7
SECTION 2 INFILTRATION HEAT LOSSES		STEP 3		
1		2		
Sub-total		3		
TOTAL		4		

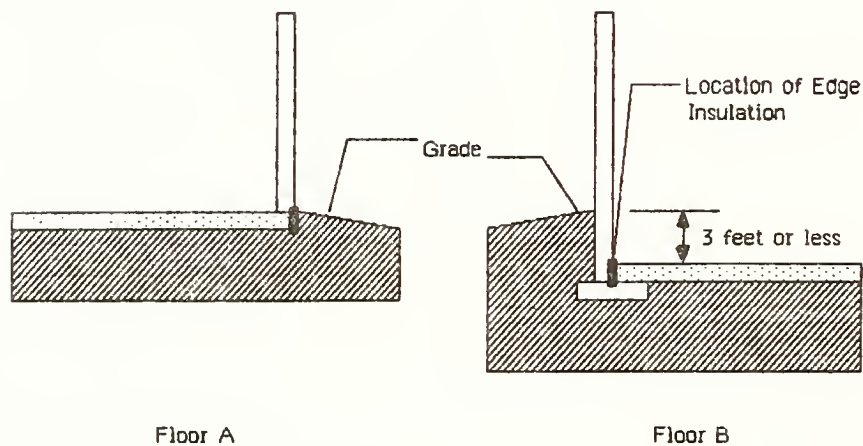
Figure 5.7 Form 5.2 Heat Loss Calculation Sheet

5.6 Transmission Heat Loss Calculations

Instructions are given for determining transmission heat losses thru the major building components followed by an example calculation for each component.

5.6.1 Floor-on-Grade

DESCRIPTION: A floor on grade, sometimes referred to as a slab-on-grade, is a floor 3 ft and less below-grade and in most cases constructed of concrete, see Figure 5.8.



Floor A is a typical floor-on-grade and Floor B is also considered a floor-on-grade, as long as the dimension shown does not exceed 3 feet.

Figure 5.8 Floor-on-Grade

PROCEDURE FOR DETERMINING HEAT LOSS

STEP 1: Calculate the perimeter distance of the floor in feet, see Figure 5.9. The perimeter distance is calculated as follows:

$$\text{perimeter} = 2(L) + 2(W) \quad (5.8)$$

where:

perimeter - is the outside distance around the floor in ft.

L - is the length of the floor in ft.

W - is the width of the floor in ft.

NOTE: A floor-on-grade does not require a U value to be determined. Therefore, the use of Form 5.1 is not required.

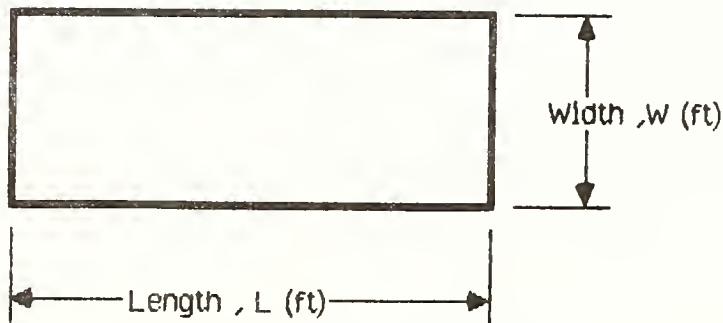


Figure 5.9 Plan View of Floor-on-Grade From Which the Perimeter of the Floor is Calculated

STEP 2: Enter Table 5.5* to select the heat loss per foot of exposed edge.

STEP 3: Calculate the heat loss through the floor by multiplying the heat loss factor with the perimeter.

Table 5.5 Heat Loss of Concrete Floors at or Near Grade Level per Foot of Exposed Edge

Outdoor Temperature	Heat Loss per Foot of Exposed Edge, Btu/(hr ft)		
	R = 5.0 Edge Insulation	R = 2.5 Edge Insulation	No Edge Insulation
-20 to -30	50	60	75
-10 to -20	45	55	65
0 to -10	40	50	60
+10 to 0	35	45	55
+20 to +10	30	40	50

EXAMPLE 1 FLOOR-ON-GRADE

Calculate the heat loss through the floor-on-grade shown below in Figure 5.10 with the following conditions:

Outside Temperature 5°F

Floor Dimensions 100 ft by 50 ft

Insulation None

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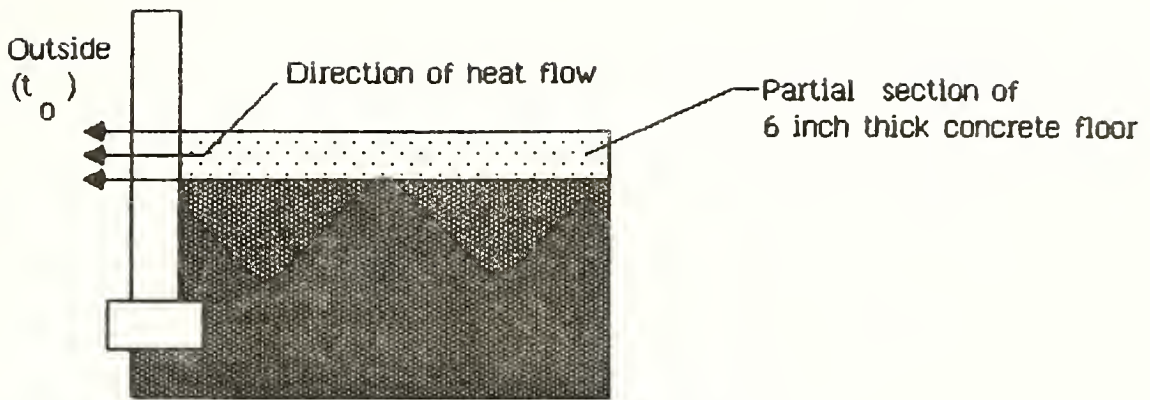


Figure 5.10 Floor Section for Example 1

SOLUTION

STEP 1: The perimeter distance is

$$\begin{aligned}\text{perimeter} &= 2(L) + 2(W) \\ \text{perimeter} &= 2(100) + 2(50) \\ \text{perimeter} &= 300 \text{ ft}\end{aligned}$$

STEP 2: From Table 5.5 the out door design temperature falls within the +10 to 0 range and with no insulation the heat loss factor is 55 BTU/(hr ft)

STEP 3: The heat loss q is

$$\begin{aligned}q &= \text{perimeter} \times \text{heat loss factor} \\ q &= (300 \text{ ft})(55 \text{ BTU}/(\text{hr ft})) \\ q &= 16,500 \text{ BTU/hr}\end{aligned}$$

5.6.2 Floor-Below-Grade

DESCRIPTION: A floor-below-grade, see Fig. 5.11, is located 3 ft or greater below-grade.

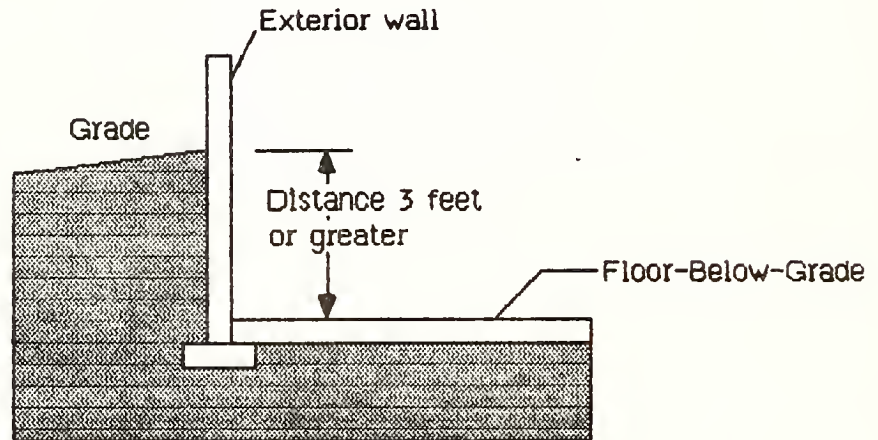


Figure 5.11 Floor-Below-Grade

PROCEDURES FOR DETERMINING HEAT LOSS

STEP 1: Determine the total U value for the floor section using Tables 5.1 and 5.2 and enter the value on Form 5.2.

STEP 2: Calculate the area of the floor and enter it on Form 5.2. The area is calculated as follows:

$$\text{Area} = (L) \times (W) \quad (5.9)$$

where:

Area - is the area of the floor in sq ft.

L - is the length of the floor measured from inside the exterior wall in ft.

W - is the width of the floor measured from inside the exterior wall in ft.

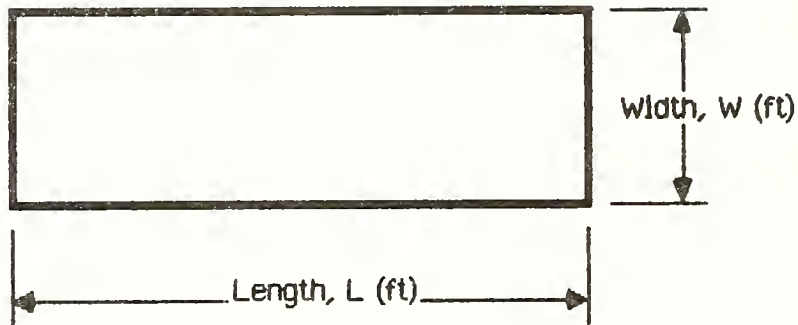


Figure 5.12 Plan View of Floor-Below-Grade

STEP 3: Calculate the temperature difference (TD) between the inside temperature and the temperature of the soil below the floor and enter the value on Form 5.2. The TD is calculated as follows:

$$TD = t_i - t_s \quad (5.10)$$

where:

t_i is the inside temperature from top of Form 5.2.

t_s is the temperature of the soil from Table 5.6.

STEP 4: Calculate the heat loss q using Eq. 5.1.

Table 5.6 Soil Temperatures for State of Indiana

Location ^a	Wall, Floor Depth (inches)	Soil Temp. (deg F)	Avg Soil Temp. (deg F)
North	0 to 36	34	36.5
	36 and deeper	39	
Central	0 to 36	36	38
	36 and deeper	40	
South	0 to 36	36	40.5
	36 and deeper	45	

^a The location refers to the top Northern third of the state, the Central third of the state, and the Southern third of the state.

EXAMPLE 2 FLOOR-BELOW-GRADE

Calculate the heat loss through the floor-below-grade shown in Fig. 5.13 below with the following conditions:

Inside Temperature 70°F
 Floor Dimensions 50 ft by 50 ft
 Insulation none

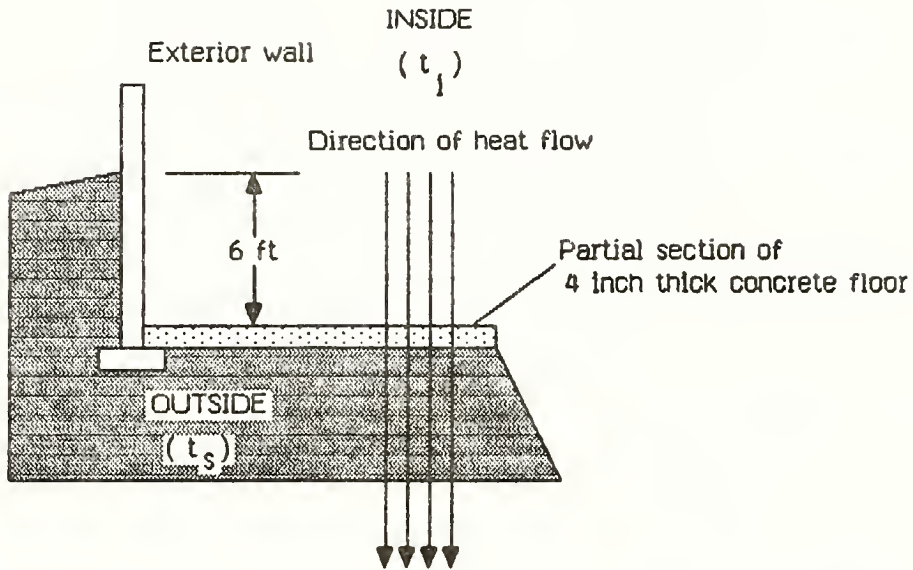


Figure 5.13 Floor Section for Example 2

SOLUTION

STEP 1: Calculate U from Tables 5.1 and 5.2 and transfer the the value to Form 5.2, see Fig. 5.14.

SECTION 1			SECTION 2					
Cross Section	Construction	Thk. IN.						
			1/k	R	U	1/k	R	U
	Inside Surface			.92				
	Concrete Floor	4	.08	.32				
	R			1.24				
	U = 1/R				.8065			

Figure 5.14 Example 2 Form 5.1

STEP 2: The total floor area is

$$\text{Area} = L \times W$$

$$\text{Area} = 50 \text{ ft} \times 50 \text{ ft}$$

$$\text{Area} = 2500 \text{ sq ft}$$

STEP 3: The TD is

$$\text{TD} = t_i - t_s$$

$$\text{TD} = 70 - 40$$

$$\text{TD} = 30^{\circ}\text{F}$$

STEP 4: The heat loss q is

$$q = U \times A \times \text{TD}$$

$$q = 0.8065 \times 2500 \text{ sq ft} \times 40^{\circ}\text{F}$$

$$q = 80,650 \text{ BTU/hr}$$

5.6.3 Wall-Below-Grade

DESCRIPTION: A wall below grade extends more than 3 ft below grade, see Fig. 5.15.

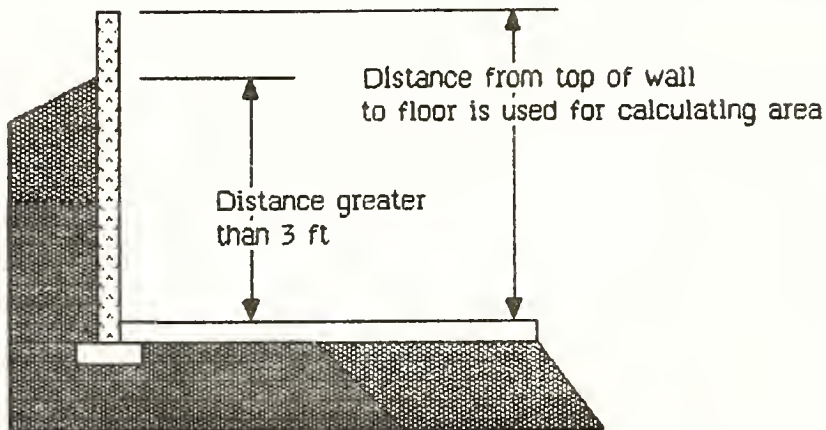


Figure 5.15 Wall-Below-Grade

PROCEDURE FOR DETERMINING HEAT LOSS

STEP 1: Determine the heat loss factor from Table 5.7* and enter this value for the U value on Form 5.2.

NOTE: It is not necessary to calculate a U value for walls-below-grade.

STEP 2: Calculate the area, see Fig. 5.16, of the wall-

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below-grade and enter the value on Form 5.2. The area is calculated as follows:

$$\text{Area} = [(L)(H)(\text{No. of walls})] - (\text{openings}) \quad (5.11)$$

where:

Area - is the area of wall-below-grade in sq ft.

L - is the length of wall in ft.

H - is the height of wall in ft.

No. of Walls - is the number of walls with same dimensions.

Openings - is the area of windows and doors in the wall in sq ft. Methods for calculating heat losses through these openings are presented later in the chapter.

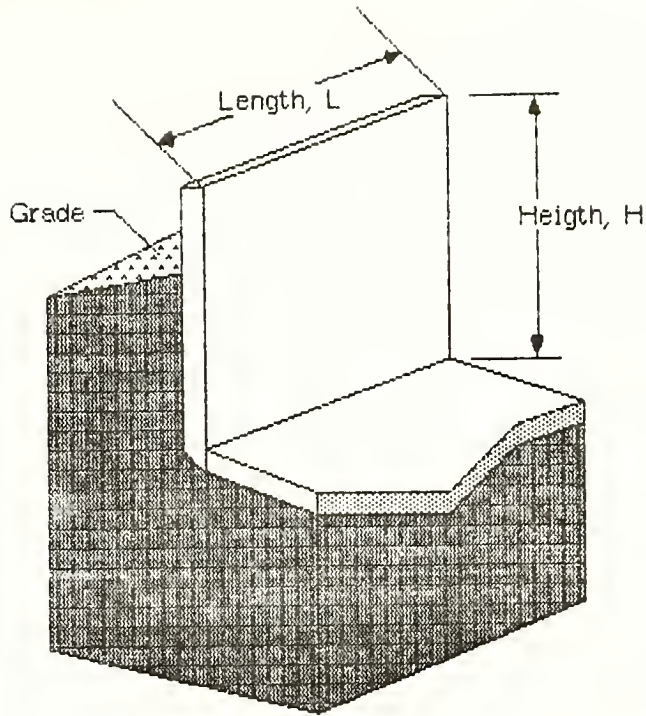


Figure 5.16 Section of Wall-Below-Grade From Which the Area is Calculated in sq. ft.

STEP 3: Calculate the TD between the inside temperature and the average temperature of the soil and enter the value on Form 5.2. The TD is calculated as follows:

$$TD = t_i - t_{\text{avg}} \quad (5.12)$$

where:

TD is the temperature difference.

t_i is the inside temperature from Form 5.2.

t_{avg} is the average soil temperature from Table 5.6.

STEP 4: Calculate the heat loss q using Eq. 5.1.

Table 5.7 Heat Loss for Below-Grade Walls

Distance Wall Extends Below- Grade, † ft	Insulation Over Full Surface			Wall Insulated to a Depth of Two Feet Below Grade		
	R-4	R-8	R-13	R-4	R-8	R-13
4	0.110	0.075	0.057	0.136	0.102	0.090
5	0.102	0.071	0.054	0.128	0.100	0.091
6	0.095	0.067	0.052	0.120	0.097	0.089
7	0.089	0.064	0.050	0.112	0.093	0.086

† For a depth below-grade of 3 feet or less, treat as a slab on grade.

EXAMPLE 3 WALL-BELOW-GRADE

Calculate the heat loss through the wall-below-grade shown in Fig. 5.17 below with the following conditions:

Inside Temperature 70°F

Wall Dimensions four at 8 ft high by 50 ft long

Openings two doors at 3 ft by 7 ft
four windows at 4 ft by 4 ft

Insulation R-4 over full surface

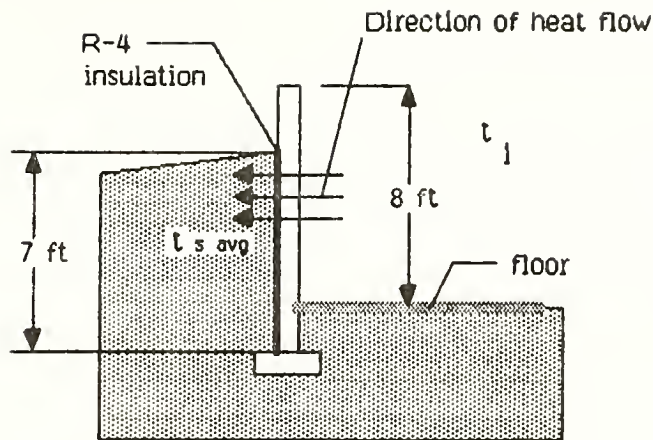


Figure 5.17 Wall Section for Example 3

SOLUTION

STEP 1: From Table 5.7, the wall extends 7 ft below grade with R-4 insulation over the entire surface, the heat loss factor is 0.089.

STEP 2: The area is

$$\text{Area} = [(H)(L)(\text{NO. of Walls})] - (\text{openings})$$

$$\text{Area} = [(8 \text{ ft})(50 \text{ ft}) 4] - [2(3 \text{ ft})(7 \text{ ft}) + 4(4 \text{ ft})(4 \text{ ft})]$$

$$\text{Area} = 1600 \text{ sq ft} - 106 \text{ sq ft}$$

$$\text{Area} = 1494 \text{ sq ft}$$

STEP 3: The TD is

$$\text{TD} = t_i - t_{s \text{ avg}}$$

$$\text{TD} = 70 - 38$$

$$TD = 32^{\circ}\text{F}$$

STEP 4: The heat loss q is

$$q = U \times \text{Area} \times TD$$

$$q = (0.089)(1494)(32)$$

$$q = 4255 \text{ BTU/hr}$$

5.6.4 Wall-Above-Grade

DESCRIPTION A wall-above-grade does not extend greater than 3 ft below grade, see Fig. 5.18.

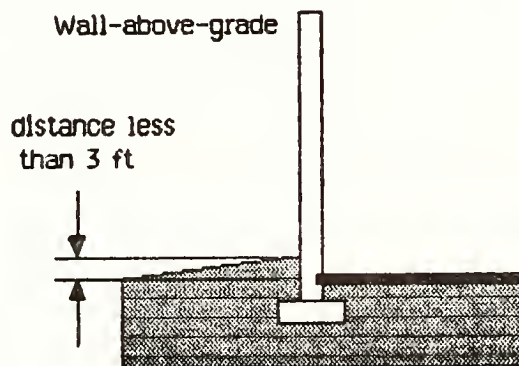


Figure 5.18 Wall-Above-Grade

PROCEDURE FOR DETERMINING HEAT LOSS

STEP 1: Determine U for the wall section and transfer the value to Form 5.2.

STEP 2: Calculate the area of the wall-above-grade (this includes any of the portion 3 ft or less below-grade) and enter the value on Form 5.2.

STEP 3: Calculate the TD between the inside temperature and the outside temperature. The TD is calculated as follows:

$$TD = t_i - t_o \quad (5.13)$$

where:

t_i and t_o are from top of Form 5.2.

STEP 4: Calculate the heat loss q using Eq. 5.1.

EXAMPLE 4A WALL-ABOVE-GRADE (one heat flow path)

Calculate the heat loss through the wall-above-grade shown in Fig. 5.19 below with the following conditions.

Inside Temperature	70 °F
Outside Temperature	3 °F
Wall Dimensions	two at 10 ft high by 25 ft long two at 10 ft high by 50 ft long
Openings	two doors at 3 ft by 7 ft five windows at 4 ft by 6 ft

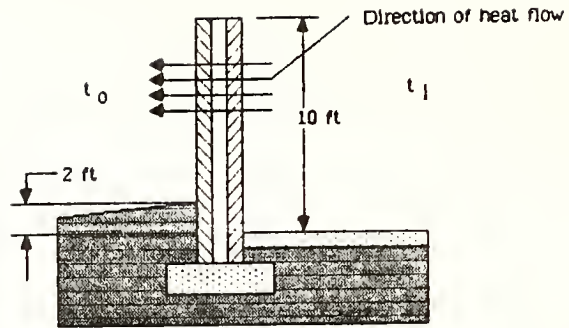


Figure 5.19 Wall Section for Example 4A

SOLUTION

STEP 1: The U value for the wall section is determined and because the wall has one heat transmission path, only one column is required on Form 5.1, see Fig. 5.20.

SECTION 1			SECTION 2					
Cross Section	Construction	Thk. IN.						
			1/k	R	U	1/k	R	U
	Outside Surface			.17				
	Brick Common	4.5	.20	.9				
	Air Space	2		.9				
	Brick Common	4.5	.20	.9				
	Plaster	0.5	.20	.1				
	Inside Surface			.68				
	R			3.65				
	U = 1/R				0.274			

Figure 5.20 Example 4A Form 5.1

STEP 2: The area is

$$\text{Area} = [(H)(L)(\text{NO. of Walls})] - (\text{openings})$$

$$\text{Area} = [(10 \text{ ft})(25 \text{ ft})2 + (10 \text{ ft})(50 \text{ ft})2] - [2(3 \text{ ft})(7 \text{ ft}) + 5(4 \text{ ft})(6 \text{ ft})]$$

$$\text{Area} = 1500 \text{ sq ft} - 162 \text{ sq ft}$$

$$\text{Area} = 1338 \text{ sq ft}$$

STEP 3: The TD is

$$\text{TD} = t_i - t_o$$

$$\text{TD} = 70 - 3$$

$$\text{TD} = 67^{\circ}\text{F}$$

STEP 4: The heat loss q is

$$q = U \times \text{Area} \times TD$$

$$q = (0.274)(1338 \text{ sq ft})(67^{\circ}\text{F})$$

$$q = 24,563 \text{ BTU/hr}$$

EXAMPLE 4B WALL-ABOVE-GRADE (2 heat flow paths)

Calculate the heat loss through the wall-above-grade shown in Fig. 5.21 below with the following conditions:

Inside Temperature 70°F

Outside Temperature 3°F

Wall Dimensions two at 8 ft high by 20 ft long
 two at 8 ft high by 40 ft long

Openings two windows at 4 ft by 6 ft
 one door at 3 ft by 7 ft
 one garage door at 10 ft by 7 ft

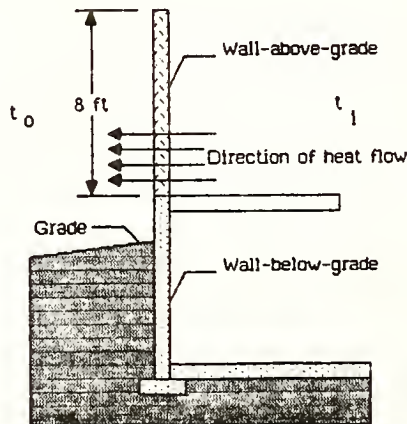


Figure 5.21 Wall Section for Example 4B.

SOLUTION

STEP 1: The U value for the wall section is determined between the framing and at the framing, see Fig. 5.22.

SECTION 1			SECTION 2					
Cross Section	Construction	Thk. IN.	Between Studs			At Studs		
			1/k	R	U	1/k	R	U
	Outside Surface			.17			.17	
	Siding Wood 0.5 x 8in.			.81			.81	
	Sheathing 0.5 asphalt Imp.			1.32			1.32	
	2x4in. wood studs 16 in o.c.			-			4.38	
	3.5 in. Batt Insulation			.11			-	
	Sheet Rock			.45			.45	
	Inside Surface			.68			.68	
	R			14.43			7.81	
	U = 1/R				.0693			.128
	U avg =							.0752

Figure 5.22 Example 4B Form 5.1

After the U value is determined for the two heat flow paths, U avg is calculated using Eq. 5.7 as follows:

Between Framing U = 0.0693

At Framing U = 0.128

From Table 5.4

2 by 16 inches on center

Between Framing 90 %

At Framing 10 %

$$U_{avg} = (0.90)(0.0693) + (0.10)(0.128)$$

$$U_{avg} = 0.0752$$

STEP 2: The area of the wall is

$$\text{Area} = [(H)(L)(\text{No. of Walls})] - (\text{openings})$$

$$\begin{aligned} \text{Area} = & [(8 \text{ ft})(20 \text{ ft}) 2] + (8 \text{ ft})(40 \text{ ft}) 2] - \\ & [2(4 \text{ ft})(6 \text{ ft}) + (3 \text{ ft})(7 \text{ ft}) + \\ & (10 \text{ ft})(7 \text{ ft})] \end{aligned}$$

$$\text{Area} = 960 \text{ sq ft} - 139 \text{ sq ft}$$

$$\text{Area} = 821 \text{ sq ft}$$

STEP 3: The TD is

$$TD = t_i - t_o$$

$$TD = 70 - 3$$

$$TD = 67^{\circ}\text{F}$$

STEP 4: The heat loss q is

$$q = U \times \text{Area} \times TD$$

$$q = (0.0752)(960 \text{ sq ft})(67^{\circ}\text{F})$$

$$q = 4,837 \text{ BTU/hr}$$

5.6.5 Partitions Separating Conditioned and Unconditioned Space

DESCRIPTION: A partition separating conditioned and unconditioned space is any interior wall or floor that separates heated space from unheated space, see Fig. 5.23.

PROCEDURE FOR DETERMINING HEAT LOSS

STEPS 1 and 2 are the same Steps 1 and 2 of Walls-Above-Grade

STEP 3: Calculate the TD between the inside temperature of the heated space and the unheated space. The TD is calculated as follows:

$$TD = t_i - t_{i'}, \quad (5.14)$$

where:

TD is the temperature difference, degrees F.

t_i is the inside temperature from Form 5.2, degrees F.

$t_{i'}$ is the temperature of the air in the unconditioned space, degrees F.

STEP 4: Calculate the heat loss q using Eq. 5.1.

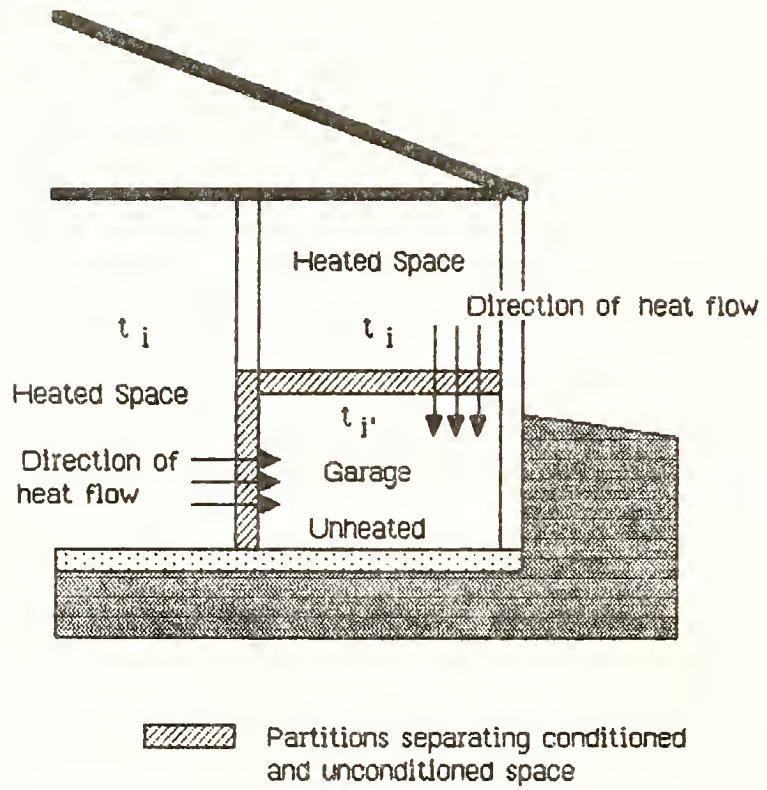


Figure 5.23 Wall and Floor Partitions Separating Conditioned and Unconditioned Space.

EXAMPLE 5 WALL PARTITION SEPARATING CONDITIONED AND UNCONDITIONED SPACE

Calculate the heat loss through the wall partition shown in Fig. 5.24 below with the following conditions:

Inside Temperature 70°F

Unconditioned Temp. 40°F

Wall Dimensions 9 ft by 50 ft

Openings one door at 3 ft by 7 ft

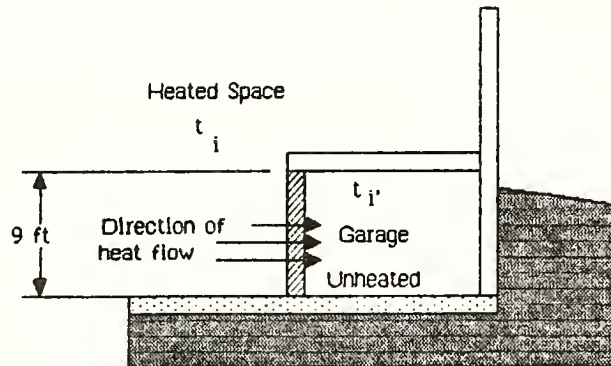


Figure 5.24 Wall Partition for Example 5

SOLUTION

STEP 1: Calculate the U values and an average U value, see Fig. 5.25.

SECTION 1			SECTION 2					
Cross Section	Construction	Thk. IN.	Between Studs			At Studs		
			1/k	R	U	1/k	R	U
	Inside Surface			.68			.68	
	Sheet Rock	0.5		.45			.45	
	2x4-in. wood stud 24 in o.c.			-			4.38	
	Air Space	3.5		.91			-	
	Concrete Block - Cinder	8		1.72			1.72	
	Inside Surface			.68			.68	
	R			4.44			7.91	
	U = 1/R				.2252			.1264
	U avg -							.2193

Figure 5.25 Example 5 Form 5.1

U avg calculated as follows:

Between Framing U = 0.2252

At Framing U = 0.1264

From Table 5.4 2 by 4 at 24 inches on center

Between Framing 94%

At Framing 6%

U avg. = (0.94)(0.2252) + (0.06)(0.1264)

U avg. = 0.2193

STEP 2: Area of wall is

Area = [(H)(L)] - (openings)

$$\text{Area} = [(9 \text{ ft})(50 \text{ ft})] - (3 \text{ ft})(7 \text{ ft})$$

$$\text{Area} = 450 \text{ sq ft} - 21 \text{ sq ft}$$

$$\text{Area} = 429 \text{ sq ft}$$

STEP 3: The TD is

$$\text{TD} = t_i - t_i'$$

$$\text{TD} = 70 - 40$$

$$\text{TD} = 30^{\circ}\text{F}$$

STEP 4: The heat loss q is

$$q = U \times \text{Area} \times \text{TD}$$

$$q = (0.2193)(429 \text{ sq ft})(30^{\circ}\text{F})$$

$$q = 2822 \text{ BTU/hr}$$

5.6.6 Roof

DESCRIPTION: A roof consists of the ceiling, joists and waterproofing membrane. The two most common types of roofs are the pitched and flat roof, see Fig. 5.26.

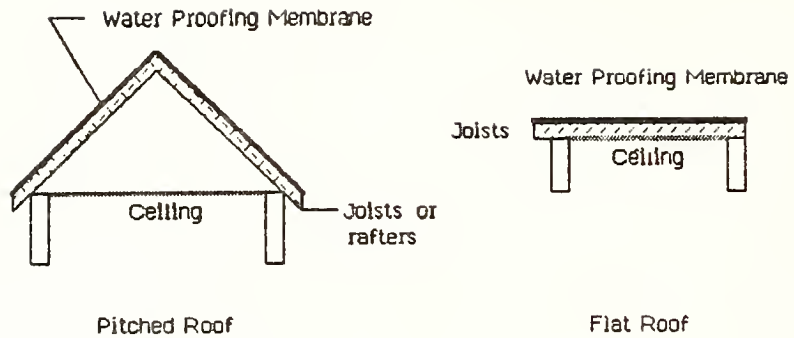


Figure 5.26 Typical Roof Construction

PROCEDURES FOR DETERMINING HEAT LOSS

- STEP 1: Determine the U for the roof construction using Tables 5.1 to 5.3 and enter the value on Form 5.2.
- STEP 2: Calculate the area of the roof, see Fig. 5.27, and enter the value on Form 5.2.

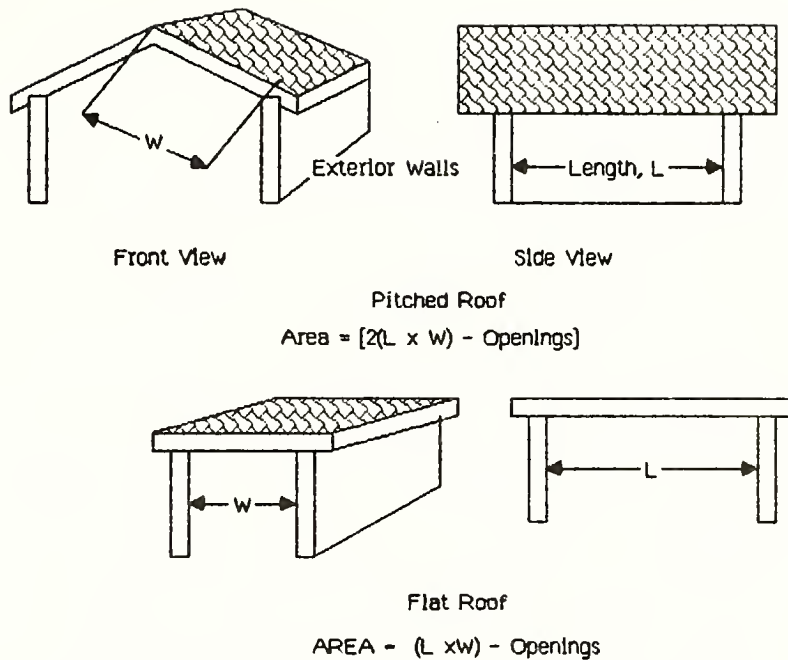


Figure 5.27 Roof Area Calculation

STEP 3: Calculate the temperature difference (TD) between the inside and outside temperatures using Eq. 5.13.

STEP 4: Calculate the heat loss (q) using Eq. 5.1.

EXAMPLE 6A PITCHED ROOF HEAT LOSS

Calculate the heat loss through the pitched roof shown in Fig. 5.27 with the following conditions:

Inside Temperature 70°F

Outside Temperature 3°F

Roof Dimensions 21 ft by 100 ft
 Pitch 4 : 12

SOLUTION

STEP 1: Calculate U and U avg from Tables 5.1, 2, 3 and 9 and enter the value of U avg on Form 5.2, see Fig. 5.28.

SECTION 1			SECTION 2					
Cross Section	Construction	Thk. IN.	Between Rafters			At Rafters		
			1/k	R	U	1/k	R	U
	Outside Surface			.17			.17	
	Asphalt Shingles			.44			.44	
	Felt Paper			.06			.06	
	Plywood Sheathing			.77			.77	
	2x4-in. wood rafters 16 in oc			-			4.38	
	Batt Insulation			11			-	
	Sheet Rock			.45			.45	
	Inside Surface			.62			.62	
	R			13.51			6.89	
	U = 1/R				.074			.145
	U avg =							.081

Figure 5.28 Example 6A Form 5.1

U avg is calculated as follows:

Between Framing U = 0.074

At Framing U = 0.145

From Table 5.4

Between Framing 90%

At Framing 10%

$$U_{avg} = (0.90)(0.074) + (0.10)(0.145)$$

$$U_{avg} = 0.081$$

STEP 2: The roof area is

$$A = 2(L \times W) - \text{openings}$$

$$A = 2(100 \text{ ft} \times 21 \text{ ft}) - 0$$

$$A = 4200 \text{ sq ft}$$

STEP 3: The TD is

$$TD = t_i - t_o$$

$$TD = 70 - 3$$

$$TD = 67^{\circ}\text{F}$$

STEP 4: The heat loss (q) is

$$q = U \times A \times TD$$

$$q = (0.081)(4200 \text{ sq ft})(67^{\circ}\text{F})$$

$$q = 22,822 \text{ BTU/hr}$$

EXAMPLE 6B FLAT ROOF

Calculate the heat loss through the flat roof shown in Fig. 5.27 with the same conditions as Example 6A.

SOLUTION

STEP 1: From Tables 5.1, 5.2, 5.3 and 5.8 the U value and U avg is calculated, see Fig. 5.29.

SECTION 1			SECTION 2					
Cross Section	Construction	Thk. IN.						
			1/k	R	U	1/k	R	U
	Outside Surface			.17			.17	
	Built up Roof			.33			.33	
	Plywood Deck	.625		.78			.78	
	2x8-in. Joists 24in o.c.			-			9.06	
	Blanket Insulation	7.5		19			-	
							.45	
	Sheet Rock	0.5		.45			.61	
	Inside Surface			.61				
	R			21.34			11.4	
	U = 1/R				.0469			.0877
	U avg -							.0493

Figure 5.29 Example 6B Form 5.1

U avg is calculated as follows:

Between Framing U = 0.0469

At Framing U = 0.0877

From Table 5.4

Between Framing 96%

At Framing 4%

$$U_{avg} = (0.0469)(0.96) + (0.0877)(0.04)$$

$$U_{avg} = 0.0493$$

STEP 2: The roof area is

$$A = (L \times W) - \text{openings}$$

$$A = (40 \text{ ft} \times 100 \text{ ft}) - 0$$

$$A = 4000 \text{ sq ft}$$

STEP 3: The TD is

$$TD = t_i - t_o$$

$$TD = 70 - 3$$

$$TD = 70^{\circ}\text{F}$$

STEP 4: The heat loss (q) is

$$q = U \times A \times TD$$

$$q = (0.0493)(4000 \text{ sq ft})(67^{\circ}\text{F})$$

$$q = 13,212 \text{ BTU/hr}$$

5.6.7 Windows and Skylights

DESCRIPTION: Windows and skylights are composed of any translucent material, usually glass, for the purpose of illumination and/or visual aspects, see Fig. 5.30.

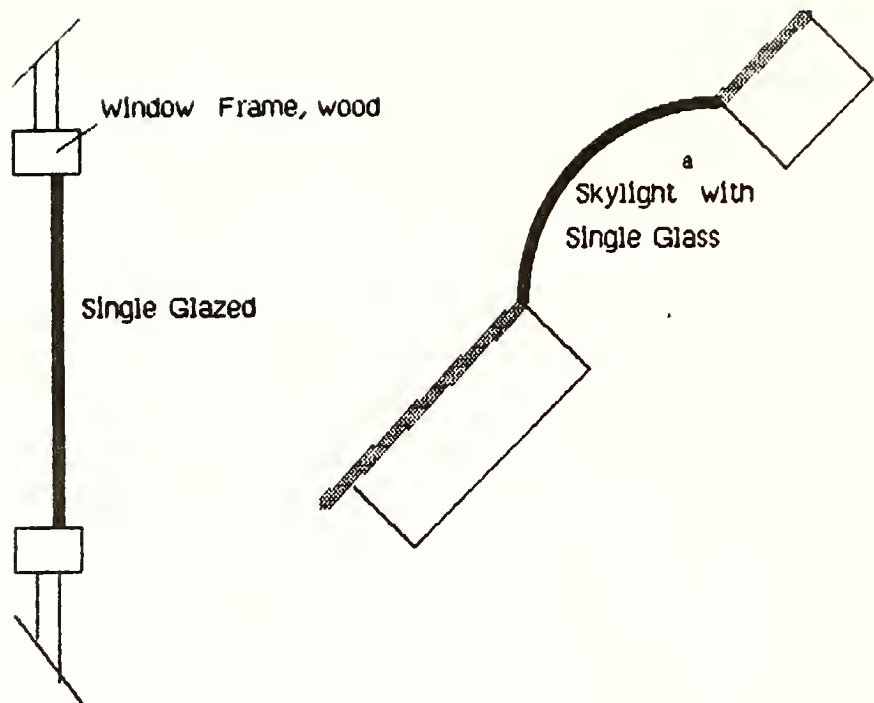


Figure 5.30 Typical Window and Skylight

PROCEDURE FOR DETERMINING HEAT LOSS

STEP 1: Determine the coefficient of heat transmission from Table 5.8A* for type of window.

NOTE: For windows the use Form 5.1 is not required.

STEP 2: Determine appropriate adjustment factor from Table 5.8B*, if applicable, and multiply it with the value from Table 5.8A. Enter this value on Form 5.2.

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The procedure for determining the percent glass required in Table 5.8B is as follows:

$$\text{percent Glass} = \frac{(W_g)(H_g)}{(W_w)(H_w)} \times 100 \quad (5.15)$$

where:

W_g and H_g are the width and height of the exposed glass, ft.

W_w and H_w are the width and height of the window measured from outside the window frame, ft.

STEP 3: Calculate the area of the window(s) and enter the value on Form 5.2 using equation 5.16:

$$A = (W_w)(H_w)(\text{No. of windows}) \quad (5.16)$$

where:

A - is the total area of each typical window, sq. ft. (i.e. One wall may have two windows 3 ft by 4 ft and two windows 4 ft by 8 ft. Therefore, there are 2 typical 3 by 4 and 2 typical 4 by 8 windows for a total of 88 sq ft.).

W_w and H_w - are the same as in Eq. 5.15.

No. of windows - is the number of typical windows.

STEP 4: Calculate the temperature difference (TD)

STEP 5: Calculate the heat loss (q).

Table 5.8A Overall Coefficients of Heat Transmission of Windows and Skylights, BTU/(hr/ft²/F).

Description	Exterior Vertical Panels				Exterior Horizontal Panels (Skylights)	
	Summer**		Winter*		Summer ¹	Winter ¹
	No Indoor Shade	Indoor Shade***	No Indoor Shade	Indoor Shade***		
Flat Glass ^b						
Single Glass	1.04	0.81	1.10	0.83	0.83	1.23
Insulating Glass, Double ^c						
3/16 in. air space ^d	0.65	0.58	0.62	0.52	0.57	0.70
1/4 in. air space ^d	0.61	0.55	0.58	0.48	0.54	0.65
1/2 in. air space ^e	0.56	0.52	0.49	0.42	0.49	0.59
1/2 in. air space, low emittance coating ^f						
e = 0.20	0.38	0.37	0.32	0.30	0.36	0.48
e = 0.40	0.45	0.44	0.38	0.35	0.42	0.52
e = 0.60	0.51	0.48	0.43	0.38	0.46	0.56
Insulating Glass, Triple ^c						
1/4 in. air space ^d	0.44	0.40	0.39	0.31		
1/2 in. air space ^g	0.39	0.36	0.31	0.26		
Storm Windows						
1 in. to 4 in. air spaces ^d	0.50	0.48	0.50	0.42		
Plastic Bubbles ^h						
Single Walled					0.80	1.15
Double Walled					0.46	0.70

Table 5.8B Adjustment Factors for Windows (Multiply U-values in Part A by These Factors)

Description	Single Glass	Double or Triple Glass	Storm Windows
Windows			
4/4 Glass ^b	1.00	1.00	1.00
Wood Sash, 80% Glass	0.90	0.95	0.90
Wood Sash, 60% Glass	0.80	0.85	0.80
Metal Sash, 80% Glass	1.00	1.20 ^m	1.20 ^m
Sliding Patio Doors			
Wood Frame	0.95	1.00	
Metal Frame	1.00	1.10 ^m	

^aSee Table 5.14B for adjustments for various windows and sliding patio doors.

^bEntrance of insulated glass surface = 0.84.

^cDouble and triple refer to number of lights of glass.

^d0.125-in. glass.

^e0.75-in. glass.

^fCoating on either glass surface facing air space; all other glass surfaces uncoated.

^gWindow design: 0.25-in. glass, 0.125-in. glass, 0.25-in. glass.

^hRefers to windows with negligible opaque areas.

ⁱFor heat flow up.

^jFor heat flow down.

^kBased on area of opening, not total surface area.

^mValues will be less than these when metal sash and frame incorporate thermal breaks. In some thermal break designs U-values will be equal to or less than those for the glass. Window manufacturers should be consulted for specific data.

*15 mph outdoor air velocity, 0°F outdoor air, 70°F inside air temp natural convection.

**7.5 mph outdoor air velocity, 89°F outdoor air, 75°F inside air temp natural convection, solar radiation 248.3 Btu (hr ft²).

***Values apply to tightly closed venetian and vertical blinds, draperies, and roller shades.

The reciprocal of the above U-factors is the thermal resistance, R, for each type of glazing. If tightly drawn drapes (heavy close weave) closed venetian blinds, or closely fitted roller shades are used internally, the additional R is approximately 0.29 (hr ft²/Btu). If miniature louvered solar screens are used in close proximity to the outer fenestration surface, the additional R is approximately 0.24 (hr ft²/Btu).

EXAMPLE 7 WINDOW HEAT LOSS

Calculate the heat loss through the window shown in Figure 5.30 with the following conditions:

Inside temperature 72°F
 Outside temperature 3°F
 Type Single glass, wood sash
 No. of windows 5
 Shade None

SOLUTION

STEP 1: From Table 5.8A

$$U = 1.10$$

STEP 2: Using Eq. 5.15 the percent glass is

$$\% \text{ glass} = [(3)(5)/(3.5)(5.5)] 100$$

$$\% \text{ glass} = 78\% \text{ use } 80\%$$

From Table 5.8B the Factor = 0.90

Therefore

$$U = (1.10)(0.90)$$

$$U = 0.99$$

STEP 3: Using Eq. 5.16 the area is

$$A = (3.5 \text{ ft})(5.5 \text{ ft})(5)$$

$$A = 96.25 \text{ ft}$$

STEP 4: The TD is

$$TD = 72 - 3$$

$$TD = 69^{\circ}\text{F}$$

STEP 5: The heat loss is

$$q = (0.99)(96.25 \text{ sq ft})(69^{\circ}\text{F})$$

$$q = 6,575 \text{ BTU/hr}$$

5.6.8 Doors

DESCRIPTION: Doors are used to allow passage into and out of a building.

PROCEDURE FOR DETERMINING HEAT LOSS

STEP 1: Determine coefficient of heat transmission from Table 5.9* and enter the value on Form 5.2.

STEP 2: Calculate the area of the Door(s) and enter the value on Form 5.2. The area of a door is measured from outside the frame.

STEP 3: Calculate the TD.

STEP 4: Calculate the heat loss (q).

Table 5.9 Coefficients of Transmission (U) for Slab Doors, Btu/(hr/ft²/F)*

Thickness ^a	Winter			Summer
	Solid Wood, No Storm Door	Storm Door ^b		No Storm Door
		Wood	Metal	
1-in.	0.64	0.30	0.39	0.61
1.25-in.	0.55	0.28	0.34	0.53
1.5-in.	0.49	0.27	0.33	0.47
2-in.	0.43	0.24	0.29	0.42
<i>Steel Door¹⁴</i>				
1.75-in.				
A ^c	0.59	—	—	0.58
B ^d	0.19	—	—	0.18
C ^e	0.47	—	—	0.46

^aNominal thickness.

^bValues for wood storm doors are for approximately 50% glass; for metal storm door values apply for any percent of glass.

^cA = Mineral fiber core (2 lb/ft³)

^dB = Solid urethane foam core with thermal break.

^eC = Solid polystyrene core with thermal break.

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EXAMPLE 8 DOOR HEAT LOSS

Calculate the heat loss through two man doors with the following conditions:

Inside temperature	70 °F
Outside temperature	3 °F
Type of door	Solid wood, no storm door and 1.25 in.
No. of doors	2

SOLUTION

STEP 1: From Table 5.9

$$U = 0.55$$

STEP 2: The area is

$$A = (W)(H)(\text{No. of doors})$$

$$A = (4 \text{ ft})(7 \text{ ft})(2)$$

$$A = 56 \text{ ft}^2$$

STEP 3: The TD is

$$TD = 70 - 3$$

$$TD = 67^\circ \text{F}$$

STEP 4: The heat loss is

$$q = U \times A \times TD$$

$$q = (0.55)(56 \text{ sq ft})(67^\circ \text{F})$$

$$q = 2,064 \text{ BTU/hr}$$

5.7 Infiltration Heat Loss Calculations

To calculate infiltration heat losses, first determine the amount of air in cubic feet per minute (cfm) that is entering the building through the walls, doors and windows. Equation 5.17 can be used to determine the amount of cfm entering a building through the exterior walls [4].

$$Q = A \times \frac{Q}{A} \quad (5.17)$$

where:

Q is the infiltration in cfm.

A is the outside wall area in sq ft.

$\frac{Q}{A}$ is from Figure 5.32.

The following steps should be followed in using equation 5.17.

STEP 1: Determine wind velocity from climatic section of BIF.

STEP 2: From Figure 5.31* determine $\frac{w_p w}{C_p}$.

* With permission of the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA 30329.

STEP 3: Solve for Δp_w where:

$$c_p = 0.95.$$

STEP 4: From Table 5.10* determine k .

STEP 5: Determine $\frac{Q}{A}$ from Figure 5.32* using Δp_w from step 3 and k from step 4.

STEP 6: Calculate the net outside wall area for the windward wall(s). Where the net wall area is the total wall area minus the area of any windows and doors.

STEP 7: Calculate Q using equation 5.17.

STEP 8: Calculate the heat loss using equation 5.6.

To determine the infiltration through doors and windows equation 5.18 is used.

$$Q = P \times \frac{Q}{P} \quad (5.18)$$

where:

Q is the infiltration in cfm through perimeter gaps in the windows and doors.

P is the total perimeter crack length of the windows and doors in feet.

$\frac{Q}{P}$ is from Figure 5.33*.

* With permission of the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA 30329.

The following steps are to be used in applying Eq. 5.18:

STEPS 1 to 3 same as for Eq. 5.17.

STEP 4: Determine k for windows using Table 5.11* and doors using Table 5.12*.

STEP 5: Determine $\frac{Q}{P}$ from Figure 5.33 using ΔP_w from step 3 and k from step 4.

STEP 6: Determine P where:

For windows, P is the total length of the gap between movable sections of the window and frame, and between the frame and exterior wall.

For doors, P is the total length of the gap surrounding the door and frame.

STEP 7: Calculate Q using Eq. 5.18.

After Q has been calculated for the walls, doors and windows, the total Q for the walls, doors and windows is put into Eq. 5.6 to calculate the heat loss due to infiltration.

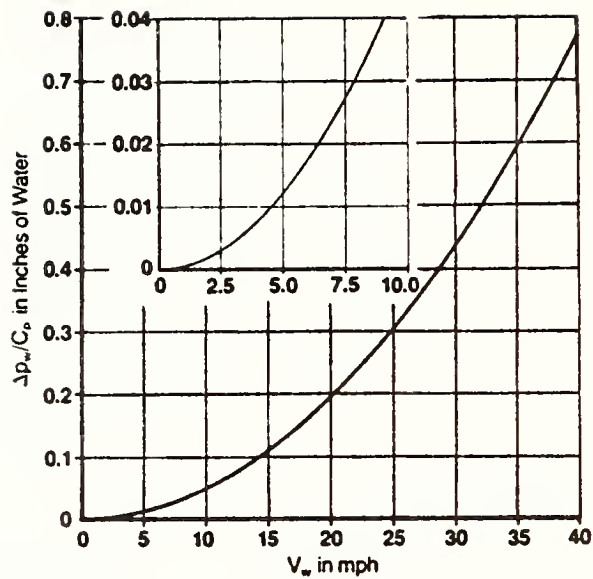


Figure 5.31 Velocity Head vs Wind Velocity

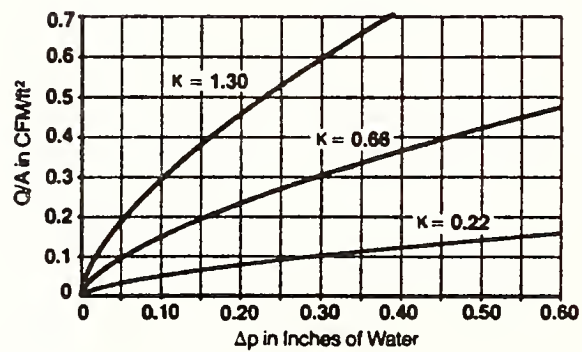


Figure 5.32 Curtain Wall Infiltration For One Room or One Floor

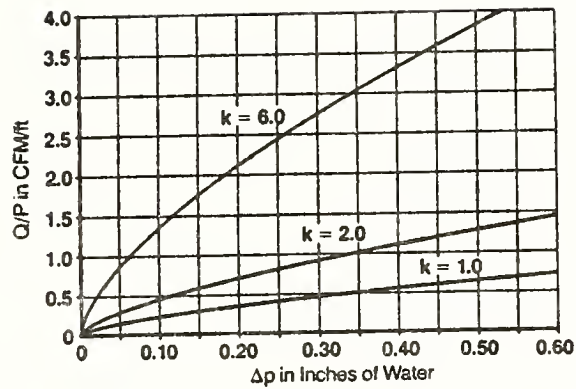


Figure 5.33 Window and Residential Type Door Infiltration Characteristics

Table 5.10 Curtain Wall Classification

Leakage Coefficient	Description	Curtain Wall Construction
$K = 0.22$	Tight Fitting Wall	Constructed under close supervision of workmanship on wall joints. When joints seals appear inadequate they must be re-done
$K = 0.66$	Average Fitting Wall	Conventional construction procedures are used
$K = 1.30$	Loose Fitting Wall	Poor construction quality control or an older building having separated wall joints

Table 5.11 Window Classification

	Wood Double-Hung (Locked)	Other Types
Tight Fitting Window $k = 1.0$	Weatherstripped Average Gap (1/64 in crack)	Wood Casement and Awning Windows; Weatherstripped Metal Casement Windows; Weatherstripped
Average Fitting Window $k = 2.0$	Non- Weatherstripped Average Gap (1/64 in. crack) or Weatherstripped Large Gap (3/32 in. crack)	All Types of Vertical and Horizontal Sliding Windows; Weatherstripped. Note: if average gap (1/64 in. crack) this could be tight fitting window Metal Casement Windows; Non-Weatherstripped Note: if large gap (3/32 in. crack) this could be a loose fitting window
Loose Fitting Window $k = 6.0$	Non- Weatherstripped Large Gap (3/32 in. crack)	Vertical and Horizontal Sliding Windows; Non- Weatherstripped

Table 5.12 Residential-Type Door Classification

Tight Fitting Door $k = 1.0$	Very small perimeter gap and perfect fit weatherstripping — often character- istic of new doors
Average Fitting Door $k = 2.0$	Small perimeter gap having stop trim fitting properly around door and Weatherstripped
Loose Fitting Door $k = 6.0$	Large perimeter gap having poor fitting stop trim and weatherstripped or Small perimeter gap with no weatherstripping

EXAMPLE 9 INFILTRATION HEAT LOSSES

Calculate the infiltration heat loss through the wall shown in Fig. 5.19 with the following conditions:

Inside Temperature	70 °F
Outside Temperature	3 °F
Windward side	North
North Wall	10 ft by 50 ft
Openings	1 door at 3 ft by 7 ft 2 windows at 4 ft by 6 ft
Window condition	non-weather stripped, large gap
Wind Velocity	15 mph

SOLUTION

Calculate cfm through North wall, first.

STEP 1: Wind velocity = 15 mph

STEP 2: From Fig. 5.31 $\frac{\Delta p_w}{C_p} = 0.12$

STEP 3: Therefore:

$$\frac{\Delta p_w}{C_p} = 0.12$$

and

$$(C_p) = 0.95.$$

Solving for Δp_w :

$$\Delta p_w = 0.12(0.95)$$

$$\Delta p_w = 0.114.$$

STEP 4: From Table 5.10 $k = 0.66$ (Average fitting wall)

STEP 5: With $\Delta p_w = 0.114$ and $k = 0.66$, from Fig. 5.32
 $\frac{Q}{A} = 0.16$

STEP 6: Calculate the outside windward net wall area.

$$\text{Total Wall Area} = 10 \text{ ft} \times 50 \text{ ft} = 500 \text{ sq ft}$$

Openings

$$\text{Door} \quad 3 \text{ ft} \times 7 \text{ ft} = (21 \text{ sq ft})$$

$$\text{Windows} \quad 2(4 \text{ ft} \times 6 \text{ ft}) = (48 \text{ sq ft})$$

$$\text{Net Wall Area} \quad 431 \text{ sq ft}$$

STEP 7: Calculate Q using Eq. 5.17.

$$Q = A \times \frac{Q}{A}$$

$$Q = 431 \text{ sq ft} \times 0.16$$

$$Q = 68.96 \text{ use } 69 \text{ cfm}$$

Next, calculate the cfm through the door and windows.

STEP 1 to 3: From calculating the wall cfm Δp_w is equal to
 0.114.

STEP 4: From Table 5.11 $k = 6.0$ for non-weather stripped windows.

From Table 5.12, $k = 6.0$ for loose fitting doors.

STEP 5: From Fig. 5.33, $\frac{Q}{P} = 1.45$ for both windows and doors.

STEP 6: Determining total crack length P for windows and doors:

For the door, $P = 2(3 \text{ ft} + 7 \text{ ft}) = 20 \text{ ft}$

For each window $P = 2(6) + 3(4) = 24 \text{ ft}$ per window

Therefore $P = 2(24 \text{ ft per window}) = 48 \text{ ft}$

Total $P = 20 \text{ ft} + 48 \text{ ft} = 68 \text{ ft}$

STEP 7: Calculate Q using Eq. 5.18.

$$Q = P \times \frac{Q}{P}$$

$$Q = 68 \text{ ft} (1.45)$$

$$Q = 98.6 \text{ use } 99 \text{ cfm}$$

The total Q for the wall, windows and doors equals $69 \text{ cfm} + 99 \text{ cfm}$ or 168 cfm .

Calculate the heat loss due to infiltration using Eq. 5.6.

$$q = 1.08 \times TD \times \text{cfm}$$

$$q = 1.08 \times (70-3) \times 168 \text{ cfm}$$

$$q = 12,156 \text{ BTU/hr}$$

5.8 Determining Annual Heating Requirements

After a building's transmission and infiltration heat losses have been calculated, an estimate of its annual heating requirements can be calculated using the modified degree day formula [3]. This is an empirical formula and will give an approximate heating requirement for an average year. Therefore, the actual energy consumption for a given year will not equal the calculated average energy consumption. The best results will occur if the actual energy consumption is averaged over several years and then compared to the calculated value. The data may be difficult to obtain for several years and in this case the energy auditor will have to use his best judgement as to how accurately the calculated heating requirement matches the actual.

The importance of the actual energy consumption being equal to the calculated lies in the economic evaluation. The better the actual heat losses of a building are known, the better will be the economic evaluation of the energy conservation alternatives.

The annual heating requirement is calculated using the modified degree day formula as follows:

$$FC = \frac{q_t \times D \times 24 \times C_d}{TD \times n \times V} \quad (5.19)$$

where:

FC is the average annual fuel consumption.

q_t is the total hourly heat load due to infiltration and transmission heat losses in BTU/hr.

D is the Heating Degree Days for the building from the BIF.

C_d is the interim correction factor for heating effect degree days, see Fig. 5.34 below.

TD is the inside-outside temperature difference from the climatic section of the BIF.

n is the rated full load efficiency factor, see Table 5.13.

V is the heating value of the fuel used in the building's heating system, see Table 5.14.

The units of the annual energy consumption calculated in Eq. 5.19 are a function of the units of V. V should always be in a unit of Btu per quantity. Where the quantities are in units of fuel: lbs, gallons, watts, etc. For example, the heating value of #2 fuel oil is 140,000 BTU/gal. Therefore, the units of the heating requirement will be in gallons. This point will be shown further in the

following example and will also illustrate the use of Eq. 5.19.

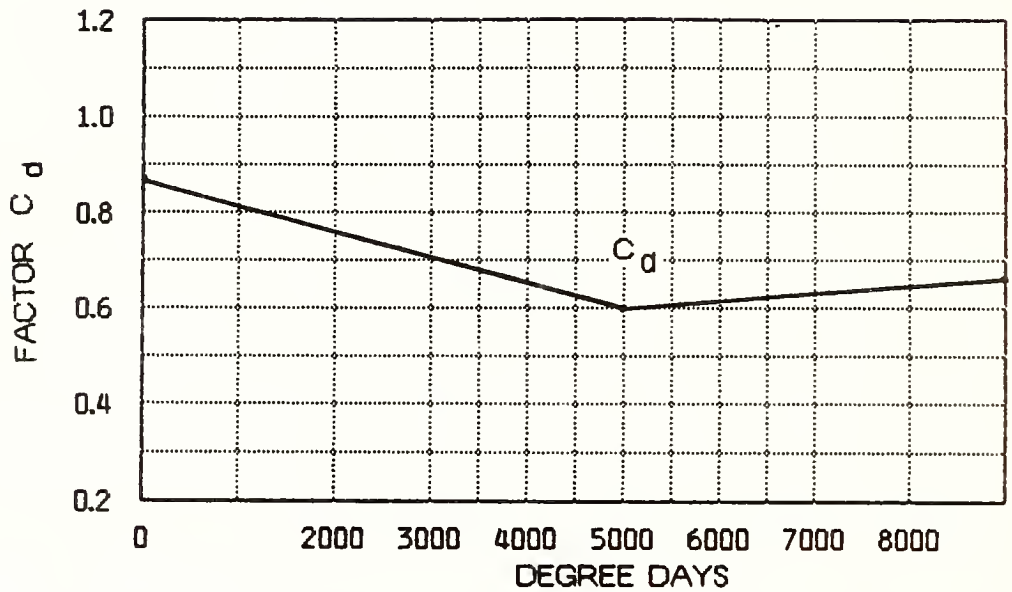


Figure 5.34 Correction Factor, C_d , vs. Degree Days [3]

Table 5.13 Full Load Efficiency (n)

Heating System Fuel	n
-----	----
Electric Resistance	1
Oil	0.65
Gas	0.55

Table 5.14 Fuel Heating Value

Fuel -----	Heating Value -----
Oil	
#2	140,000 Btu/Gal.
#6	150,000 Btu/Gal.
Electricity	3,413 Btu/kWh
Natural Gas	1,040 Btu/cf
Manufactured Gas	570 Btu/cf
Anthracite Coal	14,000 Btu/lb
Bituminous Coal	12,000 Btu/lb

5.8.1 Annual Heating Requirement Example

Determine the annual heating requirement for a building with the following conditions:

Transmission Heat Losses	140,000 BTU/hr
Infiltration Heat Losses	20,000 BTU/hr
Heating Degree Days	5000
Inside Temperature	70°F
Outside Temperature	3°F
Fuel	#2 oil
Fuel Cost	\$1.25 per gal

SOLUTION

Calculate the total gallons of fuel oil used per year

using Eq. 5.19.

$$q_t = 140,000 + 20,000 = 160,000 \text{ BTU/hr}$$

$$D = 5000$$

$$C_d = 0.6 \text{ from Fig. 5.34}$$

$$TD = 70^{\circ}\text{F} - 3^{\circ}\text{F} = 67^{\circ}\text{F}$$

$$n = 0.65 \text{ for \#2 oil from Table 5.13.}$$

$$V = 140,000 \text{ BTU/gal for \#2 oil from Table 5.14.}$$

Enter the values in Eq. 5.19:

$$FC = \frac{(160,000 \text{ BTU/hr})(5000)(24)(0.6)}{(67^{\circ}\text{F})(0.65)(140,000 \text{ BTU/gal})}$$

$$FC = 1889.5 \text{ gal}$$

Calculate the cost per year to heat the building during the winter.

$$\text{Fuel Cost} = (\text{fuel quantity})(\text{price per gallon})$$

$$\text{Fuel Cost} = (1889.5 \text{ gal})(\$1.25 \text{ per gal})$$

$$\text{Fuel Cost} = \$2,361.88 \text{ per year}$$

Therefore, the cost to heat this building during the winter is approximately \$2,362. The energy auditor will

then be able to look at the actual oil consumption from past utility bills to determine if the calculated energy consumption matches the actual. If there is a large difference, it can be caused by several factors. The two major factors being the building component materials were incorrectly identified or the variables used in Eq. 5.17 were not the proper value.

The best results will be achieved if the actual energy consumption is based on several years of past data. The energy consumption calculated from Eq. 5.17 is an average yearly consumption. Chapter 7 explains the procedures for determining actual energy consumption. After the heat losses have been determined and the energy consumption calculated, see Chapter 7 to calculate the actual energy consumption.

CHAPTER 6 LIGHTING CALCULATIONS

6.1 Introduction

Energy conservation in a building's existing lighting system can be achieved in two ways. The first way is to reduce the time the lighting system is activated. For exterior lighting, this can be accomplished through the use of timers or photocells that shut off the lights automatically. Timers can be set to shut off the lights at predetermined times when exterior lighting is not needed. However, the time schedule has to be adjusted throughout the year as the hours of available sunlight changes. Timers are therefore not as efficient as photocells at controlling exterior lighting demands. Photocells are a light sensitive device that automatically turns lights on and off with the setting and rising of the sun. The evaluation of exterior lighting is not that detailed and will only require an economic analysis of installing the photocells. The steps for completing the economic analysis are covered in Chapter 8.

The second way to conserve energy in a lighting system is to reduce the amount of power consumed. This can be accomplished by replacing existing lighting systems with a

more efficient one, by replacing individual lighting components with more efficient ones, and/or by reducing the number of light fixtures, light fixtures are also referred to as "luminaires", in use. Replacing existing lighting systems with more efficient ones requires an economic analysis to determine the payback period for the cost of replacing the existing system. This analysis will be covered in Chapter 8. Reducing the number of light fixtures, however, requires the energy auditor to evaluate the existing system and determine if reductions can be made in the number of light fixtures in use.

The purpose of this chapter is to introduce the energy auditor to the necessary calculations for evaluating the existing lighting system in order to determine if improvements can be made. The evaluation of existing lighting systems should not be taken lightly. Proper lighting is a must for a safe and productive work environment. The material that is presented in this chapter relies heavily on the IES - Illuminating Engineering Society Lighting Handbook [5] and Mechanical and Electrical Equipment for Buildings, by McGuinness, W., Stien, B., and Reynolds, J., 6th EDITION [6]. It is strongly suggested that this material be used as a reference if the need arises. Also, there are consultants who work specifically in this area and their services should be used if the need arises. The procedures presented in this chapter should at least enable the energy auditor to

determine if possible energy conservation opportunities exist in the lighting system.

6.2 Lighting Systems

The major portion of a building's lighting system consist of the interior lighting. Exterior lighting is used primarily for security lighting during the evening hours and does not constitute a major portion of the lighting electrical load. But because photocells can usually be installed at a low cost, energy savings can be achieved in the exterior lighting system without an in depth analysis. Therefore, this chapter deals primarily with the interior lighting system.

Interior lighting is necessary for individuals to carry out their daily tasks in a safe and productive manner. The level of lighting required to provide this environment is a function of the task being performed and the physical abilities of the people using the building. Tasks can range from reading blueprints to repairing automobiles, each requiring a different level of light. The amount of light a light fixture produces is a function of the number of lamps per fixture and the light-producing capabilities of each lamp. The amount of light a light fixture produces is stated in terms of its luminous output. The term "Lumen" is used to quantify the luminous output. By definition, a standard

candle burning at the center of a sphere with 1 ft radius will cause one lumen of light to fall on each square foot of interior surface of the sphere.

The main concern with evaluating an existing lighting system is the level of illumination on the visual task plane. The visual task plane is where the work activity is taking place. The visual task plane for a person sitting at a desk is shown in Figure 6.1. The amount of light that reaches the visual task plane is a function of the light fixtures luminous output which is then acted upon by the reflectance values of the ceiling, walls, floor and visual task plane. Reflectance values are given as a percentage and are a material's ability to reflect incident light. Typical values are shown for ceilings, walls and floors in Figure 6.1 and additional reflectance values are given in Table 6.1*.

Illumination is measured in terms of footcandles, abbreviated fc. If light is falling on a surface at the level of one lumen per square foot, the level of illumination at the surface is one footcandle. Footcandles are sometimes expressed in terms of "lux" where ten lux is equal to one footcandle. The level of illumination on a visual task plane is measured with a light meter as discussed in Chapter 4.

* From Shuttleworth, Riley, Mechanical and Electrical Systems for Construction, McGraw-Hill, New York, 1983.

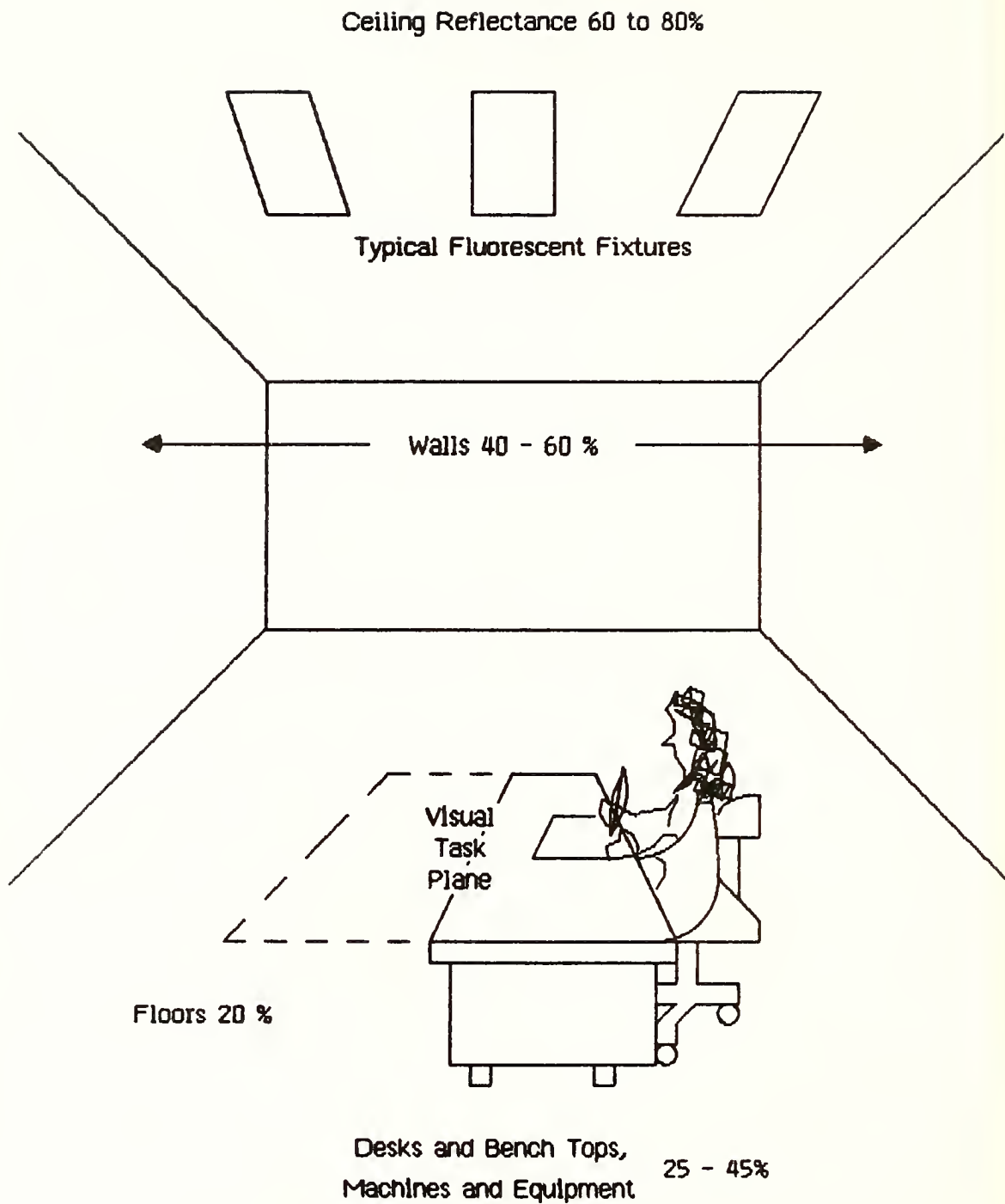


Figure 6.1 Typical Interior Lighting and Reflectance Values [7]

Table 6.1 Typical Surface Reflectances

	Percent
White Plaster	90-92
White Terra Cotta	65-80
Limestone, light color	35-65
Light Marble	70-85
Concrete, stucco, light brick	45-70
Medium-color stone (limestone and sandstone), tan and gray (rough)	20-45
Wood finishes	
Light Birch	42
Dark oak	13
Light oak	34
Dark mahogany and walnut	8
Wallpaper	
White	80
Medium color	50
Dark color	25
Paint finishes	
Gloss white	84
Flat white	82
Eggshell white	81
Ivory white	80
Primrose	78
Pearl gray	72
Ivory	71
Very light gray	70
Cream	70
Medium gray	44
Bronze	38
Sky blue	37
Tan	35
Dark gray	28
Very dark gray	19

The major component of a light fixture is the lamp. The lamp uses electricity to produce illumination. There are three major types of lamps used for interior lighting: incandescent, fluorescent and high-intensity-discharge (HID). Incandescent lamps are mainly used in residential applications and are not usually found in commercial applications. High-intensity-discharge (HID) lamps are used in applications where the color rendition is not critical. HID lamps distort the color of objects due to the type of light discharged. The primary lamp used in IDOH buildings is the fluorescent. Therefore, this chapter will be limited to the discussion of fluorescent lamps. If the need arises to analyze an incandescent or HID system, the IES LIGHTING HANDBOOK is an excellent reference.

6.2.1 Fluorescent Lighting

The basic fluorescent lamp consists of a cylindrical glass tube with an electrode assembly mounted at each end. The cylindrical glass tube is filled with a mixture of an inert gas and a small amount of mercury. An arc is activated between the two electrodes and vaporizes the mercury which releases a great amount of ultraviolet light. The tube is internally coated with phosphorescent material which fluoresces as the ultraviolet light strikes it and is transformed into visible light. Figure 6.2 shows the basic fluorescent lamp construction details.

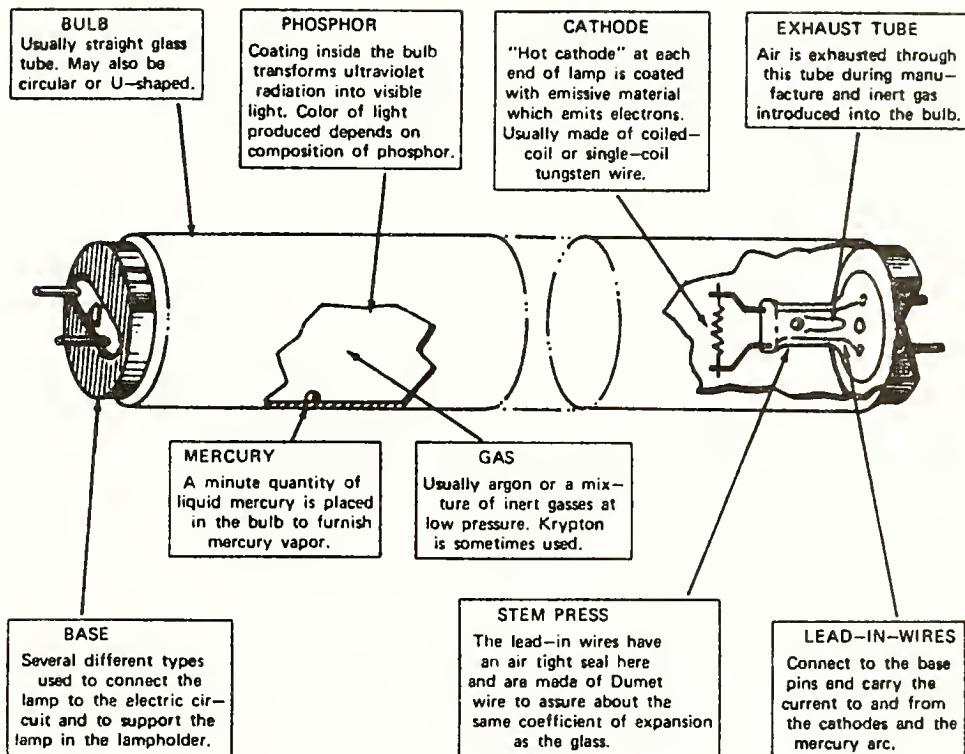


Figure 6.2 Fluorescent Lamp Construction Details [6]

Fluorescent lamps are identified with a series of letters and numbers referred to as the "lamp abbreviation". Depending upon the type of fluorescent lamp; the lamp abbreviation will indicate: lamp watts, lamp diameter and length, and color of light produced. Table 6.2* gives data for typical fluorescent lamps. From this table, additional lamp data can be determined for completing the lighting calculations. The data that must be obtained from Table 6.2 is the total watts (total watts is equal to the lamp watts plus the ballast watts) and the initial lumens.

A typical lamp abbreviation is F40T12CW. This lamp abbreviation indicates the following:

F - Fluorescent type lamp

40 - lamp watts 40

T12 - lamp diameter 12/8 of an inch

CW - lamp color Cool White

From Table 6.2, this lamp is located under the "Rapid start-preheat lamps" and the additional information can be determined.

* From McQuiness, W., Stien, B., Reynolds, J., Mechanical and Electrical Equipment for Building, 6th Edition, John Wiley & Sons, New York, 1980.

Lamp length -	48 inches
Ballast watts -	6
Total watts -	46
Lamp life -	20,000 hours
Initial output lumens -	3150
Lumens at 40% life -	2770

This type of information can be determined for fluorescent lamps by locating the lamp abbreviation in Table 6.2. It may be necessary to consult manufacturers' lamp catalogs to locate a particular lamp if it can not be located in Table 6.2.

A fluorescent lamp requires a ballast for proper starting and continued operation. Ballasts should be UL labeled and CBM/ETL certified. The UL (Underwriters Laboratories) label assures intrinsic safety. CBM (Certified Ballast Manufacturers) establishes high-quality design criteria, and ETL (Electrical Testing Laboratories) tests the ballast to determine that the design standards have been met. Ballast consume power during operation of the light fixture and when figuring the total watts per fixture the ballast watts should be included.

Table 6.2 Typical Fluorescent Lamp Data

Lamp Abbreviation	Lamp Data			Lamp Current (milliamperes)	Ballast Watts ^a	Total ^b Watts	Lamp Life (Hours) ^d	Initial Output Lumens ^e	Lumens at 40% Life	Initial		Remarks
	Lamp (Watts)	Diameter (Inches)	Length (Inches)							Actual Efficacy (lm/w) ^c	Lamp Efficacy (lm/w) ^c	
Preheat lamps ^a												
F15 T8 CW	15	1 1/8	18	425	6	23	7500	870	750	38	58	Cool white
F20 T12 CW	20	1 3/8	24	425	10	30	9000	1300	1185	43	65	
Rapid start—preheat lamps ^b												
F30 T12 CW	30	1 3/8	36	425	7 1/2	37 1/2	18000	2300	1955	61	77	
F40 T12 CW	40	1 3/8	48	425	6	46	20000	3150	2770	68	79	Warm white
F40 T12 WW	40	1 3/8	48	425	6	46	20000	3200	2770	70	80	Cool white deluxe
F40 T12 CWX	40	1 3/8	48	425	6	48	20000	2200	1825	48	55	Daylight
F40 T12 D	40	1 3/8	48	425	6	48	20000	2600	2290	57	85	Cool white deluxe
F40 T12 CW S	40	1 3/8	48	425	8	46	15000	3250	2960	71	61	High lumen maintenance
F40 T12 H	40	1 3/8	48	425	8	48	20000	2100	1745	46	53	Natural (cool) white
F40 T12 CSO	40	1 3/8	48	425	8	46	20000	2200	1890	48	55	5000 K color
F40 T12 C/S	40	1 3/8	48	425	6	48	20000	2000	1720	44	50	7500 K color
F40 T12 U	40	1 3/8	—	425	6	46	12000	2900	2525	55	63	"U" shape ^e
Rapid start—high output												
F48 T12 CW-HO	60	1 3/8	48	800	12 1/2	72 1/2	12000	4300	3740	55	72	
F60 T12 CW HO	75	1 3/8	60	800	15	90	12000	5400	4700	60	72	
F72 T12 CW HO	87	1 3/8	72	800	13	100	12000	6650	5785	67	76	
F96 T12 CW HO	112	1 3/8	96	800	14	126	12000	9200	8005	73	82	
Rapid start—very high output												
F48 T12 CW VHO	116	1 3/8	48	1500	5	121	9000	6250	4750	52	54	
F72 T12 CW VHO	168	1 3/8	72	1500	5	173	9000	9900	7720	57	59	
F96 T12 CW VHO	215	1 3/8	96	1500	10	225	9000	14500	11310	64	67	
F48 PG17 CW	116	1 3/8	48	1500	5	121	12000	7450	5950	62	64	G.E. Power Groove®
F72 PG17 CW	168	1 3/8	72	1500	5	173	12000	11500	9200	66	68	G.E. Power Groove®
F96 PG17 CW	215	1 3/8	96	1500	10	225	12000	16000	13000	71	74	G.E. Power Groove®
Instant start (Slimline) lamps												
F42 T6 CW	25	5/8	42	200	13	38	7500	1750	1490	44	70	
F64 T6 CW	38	5/8	64	200	13	51	7500	2800	2350	56	70	
F24 T12 CW	20	1 1/8	24	425	14	34	7500	1150	990	34	58	
F48 T12 CW	39	1 1/8	48	425	12	51	9000	3000	2760	54	75	
F72 T12 CW	57	1 1/8	72	425	13	73	12000	4600	4280	51	65	
F96 T12 CW	75	1 1/8	96	425	13	88	12000	6300	5800	68	84	
F36 T12	30	1 1/8	36	425	13	43	7500	2000	1740	47	67	Warm white
Energy-conserving lamps												
F40 CW/RS/	35	1 1/8	48	425	6	41	20000	2850	2510	70	81	Rapid Start, Cool white
F96 CW/HO/	95	1 3/8	96	800	14	109	12000	6500	7395	76	89	RS, High Output
F96 CW/	60	1 3/8	96	425	13	73	12000	5600	5150	76	93	Slimline, Cool white
F96 PG CW/	185	—	—	—	13	198	12000	14000	—	71	76	G.E. Power Groove®

*Data given for a preheat circuit

*Figures are for a two-lamp circuit

See Table 14.3 for typical ballast loss

*After 100-hr burning

*Includes ballast loss

*Excludes ballast loss

*U-shaped lamps available with 3 1/8- or 8-in. leg spacing, all other characteristics equal

*Designations for these lamps vary between manufacturers, thus G.E.—Wattmiser—

WM, Sylvania—Super Saver—SS, Westinghouse—Econowatt—EW

6.3 Required Material for Completing Lighting Calculations

- * Completed BIF

- * Tables 6.1 to 6.7

- * Figure 6.5

- * Form 6.1 Zonal Cavity Calculation Form, see Appendix A

- * Calculator

- * Pencil

6.4 Lighting Calculation Procedures

Illumination levels in a building can be measured directly using a light meter and/or by direct calculation. The optimal situation is to first measure the lighting levels with a light meter during the site visit and then calculate the lighting levels. This will enable the energy auditor to double check the two methods. However, lighting levels will be higher than the calculated value if measured when natural lighting is present.

The procedure for calculating interior lighting is the Zonal Cavity Method. The Zonal Cavity Method allows the energy auditor to evaluate each room's lighting requirements separately. Each room is divided into a ceiling cavity,

room cavity and a floor cavity. The reflectance value of each cavity and the desired footcandle level are then used to determine the number of light fixtures that are needed to provide the specified footcandle level. Therefore, the first step in the lighting calculation procedure is to determine the level of lighting required for the visual task.

After the lighting level is established, the Zonal Cavity Method is used to calculate the number of light fixtures that are required. Based on this calculated number, a comparison to the actual number of light fixtures being used can be made. If the calculated number is less than the actual, there is a good possibility that a change in the lighting system can be made that will produce energy savings.

6.4.1 Lighting Level Determination

The following procedures establish the lighting level for a given room based on the task or work activity taking place [5].

STEP 1: Define "Visual Task" using the type of activity taking place in the room. An example of a visual task would be "service repairs" to a vehicle.

STEP 2: Select "Illuminance Category" from Table 6.3*, Parts I and II. Nine ranges of Illuminance Categories have been established. The nine ranges are designated "A" through "I", covering illuminance levels from 20 to 20,000 lux or 2 to 200 footcandles.

STEP 3: Determine "Illuminance Range", using Illuminance Category (Step 2) from Table 6.4* based on the average age of the workers in the room, the importance for speed and/or accuracy in completing the visual task, and the task background reflectance. The illuminance values in Table 6.4 are in terms of lux. Divide this value by 10 to put the illuminance value in terms of footcandles.

* From IES Lighting Handbook Application Volume 1981, Illuminating Engineering Society of North America, New York, 1981.

Table 6.3 **Currently Recommended Illuminance Categories and Illuminance Values for Lighting Design-Target Maintained Levels**

I. Illuminance Categories and Illuminance Values for Generic Types of Activities in Interiors				
Type of Activity	Illuminance Category	Ranges of Illuminances		Reference Work-Plane
		Lux	Footcandles	
Public spaces with dark surroundings	A	20-30-50	2-3-5	General lighting throughout spaces
Simple orientation for short temporary visits	B	50-75-100	5-7.5-10	
Working spaces where visual tasks are only occasionally performed	C	100-150-200	10-15-20	
Performance of visual tasks of high contrast or large size	D	200-300-500	20-30-50	Illuminance on task
Performance of visual tasks of medium contrast or small size	E	500-750-1000	50-75-100	
Performance of visual tasks of low contrast or very small size	F	1000-1500-2000	100-150-200	
Performance of visual tasks of low contrast and very small size over a prolonged period	G	2000-3000-5000	200-300-500	
Performance of very prolonged and exacting visual tasks	H	5000-7500-10000	500-750-1000	Illuminance on task, obtained by a combination of general and local (supplementary lighting)
Performance of very special visual tasks of extremely low contrast and small size	I	10000-15000-20000	1000-1500-2000	

Table 6.3 Continued

II. Continued...	
Area/Activity	Illuminance Category
Auditoriums	
Assembly	C
Social activity	B
Conference rooms	
Conferring	D
Critical seeing (refer to individual task)	
Drafting	
Mylar	
High contrast media, India ink, plastic leads, soft graphite leads	E
Low contrast media; hard graphite leads	F
Vellum	
High contrast	E
Low contrast	F
Tracing paper	
High contrast	E
Low contrast	F
Overlays	
Light table	C
Prints	
Blue line	E
Blueprints	E
Sepia prints	F
Educational facilities	
Classrooms	
General (see Reading)	
Drafting (see Drafting)	
Science laboratories	E
Lecture rooms	
Audience (see Reading)	
Demonstration	F
Shops (see Part III, Industrial Group)	
Sight saving rooms	F
Study halls (see Reading)	
Typing (see Reading)	

Table 6.3 Continued

II. Continued...	
Area/Activity	Illuminance Category
Elevators, freight and passenger	C
Exhibition halls	C
Food service facilities	
Dining areas	
Cashier	D
Cleaning	C
Dining	B
Kitchen	E
Graphic design and material	
Color selection	F
Charting and mapping	F
Graphs	E
Keylining	F
Layout and artwork	F
Photographs, moderate detail	E
Kitchens (see Food service facilities)	
Libraries	
Reading areas (see Reading)	
Book stacks (vertical 760 millimeters (30 inches) above floor)	
Active stacks	D
Inactive stacks	B
Book repair and binding	D
Cataloging	D
Card files	E
Carrels, individual study areas (see Reading)	
Circulation desks	D
Map, picture and print rooms (see Graphic design and material)	
Audiovisual areas	D
Audio listening areas	D
Microform areas (see Reading)	
Locker rooms	C

Table 6.3 Continued

II. Continued...	
Area/Activity	Illuminance Category
Offices	
Accounting (see Reading)	
Conference areas (see Conference rooms)	
Drafting (see Drafting)	
General and private offices (see Reading)	
Libraries (see Libraries)	
Lobbies, lounges and reception areas	C
Mail sorting	E
Off-set printing and duplicating area	D
Reading	
Copied tasks	
Ditto copy	E
Micro-fiche reader	B
Mimeograph	D
Photographs, moderate detail	E
Thermal copy, poor copy	F
Xerograph	D
Xerography, 3rd generation and greater	E
Electronic data processing tasks	
CRT screens	B
Impact printer	
good ribbon	D
poor ribbon	E
2nd carbon and greater	E
Ink jet printer	D
Keyboard reading	D
Machine rooms	
Active operations	D
Tape storage	D
Machine area	C
Equipment service	E
Thermal print	E
Handwritten tasks	
#3 pencil and softer leads	E
#4 pencil and harder leads	F
Ball-point pen	D
Felt-tip pen	D
Handwritten carbon copies	E
Non photographically reproducible colors	F
Chalkboards	E

Table 6.3 Continued

II. Continued...	
Area/Activity	Illuminance Category
Printed tasks	
6 point type	E
8 and 10 point type	D
Glossy magazines	D
Maps	E
Newsprint	D
Typed originals	D
Typed 2nd carbon and later	E
Telephone books	E
Service spaces (see also Storage rooms)	
Stairways, corridors	C
Elevators, freight and passenger	C
Toilets and wash rooms	C
Stairways (see Service spaces)	
Storage rooms (see Part III, Industrial Group)	
Toilets and washrooms	C

Table 6.3 Continued

III. Industrial Group	
Area/Activity	Illuminance Category
Assembly	
Simple	D
Moderately difficult	E
Difficult	F
Very difficult	G
Exacting	H
Garages--service	
Repairs	E
Active traffic areas	C
Write-up	D
Inspection	
Simple	D
Moderately difficult	E
Difficult	F
Very difficult	G
Exacting	H
Machine Shops	
Rough bench or machine work	D
Medium bench or machine work, ordinary automatic machines, rough grinding, medium buffing and polishing	E
Fine bench or machine work, fine automatic machines, medium grinding, fine buffing and polishing	G
Extra-fine bench or machine work, grinding, fine work	H
Materials handling	
Wrapping, packing, labeling	D
Picking stock, classifying	D
Loading, inside truck bodies and freight cars	C
Paint manufacturing	
Processing	D
Mix comparison	F

Table 6.3 Continued

III. Continued	
Area/Activity	Illuminance Category
Paint shops	
Dipping, simple spraying, firing	D
Rubbing, ordinary hand painting and finishing art, stencil and special spraying	D
Fine hand painting and finishing	E
Extra-fine hand painting and finishing	G
Service spaces (see also Storage rooms)	
Stairways, corridors	B
Elevators, freight and passenger	B
Toilets and wash rooms	C
Storage rooms or warehouses	
Inactive	B
Active	
Rough, bulky items	C
Small items	D

Table 6.4 Illuminance Values, Maintained, in Lux, for a Combination of Illuminance Categories and User, Room and Task Characteristics

a General Lighting Throughout Room				
Weighting Factors		Illuminance Categories		
Average of Occupants Ages	Average Room Surface Reflectance (per cent)	A	B	C
Under 40	Over 70	20	50	100
	30-70	20	50	100
	Under 30	20	50	100
40-55	Over 70	20	50	100
	30-70	30	75	150
	Under 30	50	100	200
Over 55	Over 70	30	75	150
	30-70	50	100	200
	Under 30	50	100	200

b Illuminance on Task								
Weighting Factors			Illuminance Categories					
Average of Workers Ages	Demand for Speed and/or Accuracy*	Task Background Reflectance (per cent)	D	E	F	G**	H**	I**
Under 40	NI	Over 70	200	500	1000	2000	5000	10000
		30-70	200	500	1000	2000	5000	10000
		Under 30	300	750	1500	3000	7500	15000
	I	Over 70	200	500	1000	2000	5000	10000
		30-70	300	750	1500	3000	7500	15000
		Under 30	300	750	1500	3000	7500	15000
	C	Over 70	300	750	1500	3000	7500	15000
		30-70	300	750	1500	3000	7500	15000
		Under 30	300	750	1500	3000	7500	15000
40-55	NI	Over 70	200	500	1000	2000	5000	10000
		30-70	300	750	1500	3000	7500	15000
		Under 30	300	750	1500	3000	7500	15000
	I	Over 70	300	750	1500	3000	7500	15000
		30-70	300	750	1500	3000	7500	15000
		Under 30	300	750	1500	3000	7500	15000
	C	Over 70	300	750	1500	3000	7500	15000
		30-70	300	750	1500	3000	7500	15000
		Under 30	500	1000	2000	5000	10000	20000
Over 55	NI	Over 70	300	750	1500	3000	7500	15000
		30-70	300	750	1500	3000	7500	15000
		Under 30	300	750	1500	3000	7500	15000
	I	Over 70	300	750	1500	3000	7500	15000
		30-70	300	750	1500	3000	7500	15000
		Under 30	500	1000	2000	5000	10000	20000
	C	Over 70	300	750	1500	3000	7500	15000
		30-70	500	1000	2000	5000	10000	20000
		Under 30	500	1000	2000	5000	10000	20000

* NI = not important, I = important, and C = critical

** Obtained by a combination of general and supplementary lighting

6.4.2 Lighting Level Determination Example

Determine the required lighting level for the conference room located in the basement of the example building shown in Figure 3.3. The following information has been determined from the site visit.

Average age- 40-55 years

Task- Conferring (see Conference rooms and Reading Xerography copies, 3rd generation, Table 6.3)

Demand for speed- Important (I)

Avg measured light level- 82.5 fc

Lamp type- F40T12CW

SOLUTION

STEP 1: Define visual task: conferring

STEP 2: Select Illuminance Category from Table 6.3.

Conference Rooms

Conferring D

Critical seeing (refer to individual task)

Reading Xerography, 3rd generation E

STEP 3: Determine Illuminance Range within the Illuminance Category "D" and "E" using the following information:

Average of workers ages	40-55 yrs
Demand for speed	I
Task Background Reflectance	30-70%

From Table 6.4 under illuminance category D the flux is equal to 300 and under E the flux is 750. Therefore, the level of illumination that should be maintained in the conference room is 750 lux divided by 10 which equals 75 fc. In situations where there are more than one type of visual task, the visual task requiring the greater fc controls.

6.4.3 Zonal Cavity Lighting Calculations

Form 6.1 is provided to enable the lighting calculations to be done in a systematic manner, see Figure 6.3. The following instructions explain the steps to take in using this form [6].

Fill in general information at the top of the form. The average maintained illumination for design is the footcandle number determined in section 6.4.2. The remaining information should be determined during the site visit.

FORM 6.1 Zonal Cavity Calculation Form

GENERAL INFORMATION

Building and Room Identification _____

Average maintained illumination for design: _____ fc

Lamp Data:

Luminaire data:

Type and color: _____

Manufacture: _____

Number per luminaire: _____

Catalog number: _____

Total lumens per luminaire: _____

SELECTION OF COEFFICIENT OF UTILIZATION

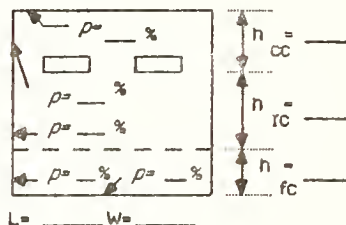
STEP 1: Fill in sketch at right.

STEP 2: Determine Cavity Ratios by formulas.

Room Cavity Ratio, RCR = _____

Ceiling Cavity Ratio, CCR = _____

Floor Cavity Ratio, FCR = _____

STEP 3: Obtain effective ceiling cavity reflectance (ρ_{cc}) from Table 6.5. ρ_{cc} = _____STEP 4: Obtain effective floor cavity reflectance (ρ_{fc}) from Table 6.5. ρ_{fc} = _____

STEP 5: Obtain coefficient of utilization (CU) from Table 6.6.

CU = _____

SELECTION OF LIGHT LOSS FACTORS

STEP 6: Determine Light Loss Factors

Unrecoverable
Luminaire ambient temperature _____Recoverable
Room surface dirt depreciation _____

Voltage to luminaire _____

Lamp lumen depreciation _____

Ballast factor _____

Lamp burnouts factor _____

Luminaire surface depreciation _____

Luminaire dirt depreciation LDD _____

Total light loss factor, LLF (product of individual factors above): _____

CALCULATIONS

STEP 7: Complete Calculations as follows:

(Average Maintained Illumination Level)

$$\text{Number of luminaires} = \frac{(\text{footcandles}) \times (\text{Area in square feet})}{(\text{Lumens per luminaire}) \times (\text{CU}) \times (\text{LLF})} \quad (\text{Eq. 6.4})$$

$$\text{Footcandles} = \frac{(\text{Number of luminaires}) \times (\text{Lumens per luminaire}) \times (\text{CU}) \times (\text{LLF})}{(\text{Room Area, } L \times W, \text{ in sq ft})} \quad (\text{Eq. 6.5})$$

$$\text{Footcandles} = \dots$$

Calculated by: _____

Date: _____

STEP 1: Fill in sketch. The room is divided into three cavities see Figure 6.4. The ceiling cavity is the space between the fixture and the ceiling. For most office type applications, fluorescent fixtures are mounted directly to the ceiling (surface mounted) and therefore the ceiling cavity is equal to zero. The room cavity is the space between the light fixture and the visual task plane. The floor cavity is the space between the bottom of the visual task plane and the top of the floor. The height of the ceiling cavity is labeled h_{CC} and is the distance in feet from the ceiling to the light fixture plane. The room cavity height is labeled h_{RC} and is the distance in feet from the light fixture plane to the visual task plane. The height of the floor cavity is labeled h_{FC} and is the distance in feet from the visual task plane to the top of the floor. In offices and many other occupancies the work plane is 30 in or 2.5 ft. In drafting rooms it is 36 to 38 in., in shops 42 to 48 in.

Enter the length (L) and width (W) of the room in feet.

Enter the reflectance values for the ceiling cavity, room cavity, and floor cavity. Reflectance values can be determined by locating the surface

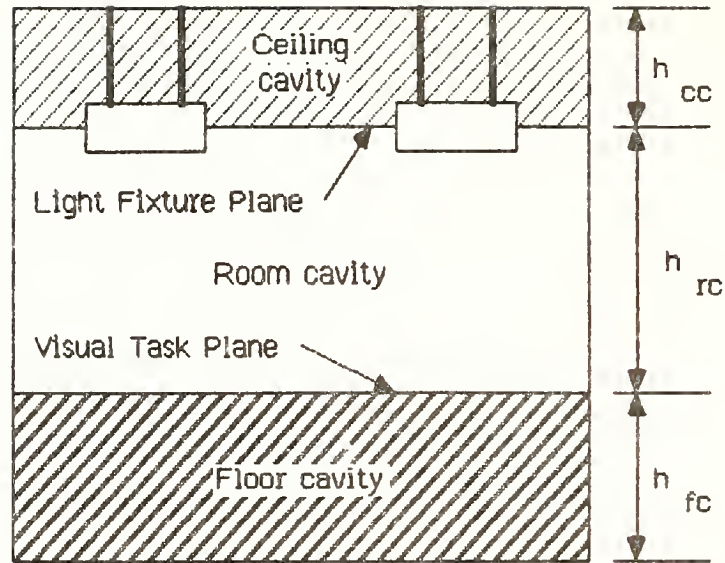


Figure 6.4 Zonal Cavity Room Cavities [6]

material of the cavity in Table 6.1. If a cavity material cannot be matched with the ones in Table 6.1, use the following values: ceiling reflectance 80%, wall reflectance 50%, and floor reflectance 20%.

STEP 2: Determine Room Cavity Ratio (RCR) using Eq. 6.1, Ceiling Cavity Ratio (CCR) using Eq. 6.2, and Floor Cavity Ratio (FCR) using Eq. 6.3.

$$RCR = 5h_{rc} \frac{L+W}{L \times W} \quad (6.1)$$

where:

h_{rc} is the height of the room cavity from Step 1.

L and W are the length and width of the room from Step 1.

$$CCR = 5h_{cc} \frac{L+W}{L \times W} \quad (6.2)$$

where:

h_{cc} is the height of the ceiling cavity from Step 1.

L and W are the same as in Eq. 6.1.

$$FCR = 5h_{fc} \frac{L+W}{L \times W} \quad (6.3)$$

where:

h_{fc} is the height of the floor cavity from Step 1.

L and W are the same as in Eq. 6.1.

STEP 3: Obtain effective ceiling cavity reflectance (ρ_{cc}) from Table 6.5*. Note that the wall reflectance remains as selected in Step 1. If the light fixtures are surface mounted or recessed, then $CCR = 0$ and ρ_{cc} = selected ceiling reflectance.

- STEP 4: Obtain effective floor cavity reflectance (ρ_{fc}) from Table 6.5. If the floor is the working plane, $FCR = 0$ and ρ_{fc} = selected floor reflectance.
- STEP 5: Obtain coefficient of utilization (CU) from Table 6.6*. Table 6.6 is a selection of common light fixtures. Select the fixture from this table that resembles the one in the particular room being analyzed. If Table 6.6 does not have a similar fixture, consult the manufacturer's data for coefficients of utilization. Note some interpolation may be necessary, since all CU data are given for an effective floor cavity reflectance of 20%. Table 6.7* gives correction factors for reflectance values of 30 and 10%. This correction factor should be used when the effective floor cavity reflectance is 30 or 10%.
- STEP 6: Determine Unrecoverable and Recoverable Light Loss Factors. The luminous output rating for lamps in Table 6.2 is the initial output of the lamp. This initial level is reduced by the effect of temperature and voltage variations, dirt accumulation on luminaires and room surfaces, lamp output depreciation, and maintenance conditions. These factors

* From McQuinness, W., Stien, B., Reynolds, J., Mechanical and Electrical Equipment for Building, 6th Edition, John Wiley & Sons, New York, 1980.

are collectively referred to as the Light Loss Factor (LLF). The LLF is determined by the following component factors:

- a. Luminaire Ambient Temperature - Light output is reduced when a fixture operates at other than its design temperature. Use "1" for normal indoor installation.
- b. Voltage to Luminaire - Use "1" for normal indoor installation.
- c. Ballast Factor - Lumen depreciation occurs when a ballast other than the one used to test the lumen output is used in the fixture. Use a value of 1.
- d. Luminaire Surface Depreciation - This results from deterioration in the fixture's reflecting surfaces (not dirt), and is proportional to the fixtures age.

The component factors a thru d above are nonrecoverable and can not be improved through normal maintenance. For the purposes of analyzing an existing lighting system, use 0.9 for the product of $a \times b \times c \times d$.

- e. Room Surface Dirt - This factor is

self-explanatory and the following values should be used.

Clean Room, frequent maintenance:	0.95.
Medium conditions and frequency of cleaning:	0.90.
Dirty room, infrequent maintenance:	0.85.

- f. Lamp Lumen Depreciation - This factor depends upon the type of lamp used and the maintenance routine for replacing lamps. Lamps can be replaced on a group basis. This constitutes replacing a group of lamps at the same time prior to lamp burnout. The second alternative is to replace individual lamps as they burnout. Use the following values:

	Group Replacement	Replacement on Burnout
Incandescent	0.94	0.88
Fluorescent	0.90	0.85
High-pressure Sodium	0.94	0.88

- g. Burnouts - This factor depends on maintenance schedules and method of replacement. Use the following values:

Group replacement of lamps:	1.0.
Individual replacement on burnout:	0.95.

h. Luminaire Dirt Depreciation (LDD) - This factor depends on the luminaire design, atmosphere conditions in the space, and maintenance schedule. The maintenance category is obtained from Table 6.6. The type of atmosphere is determined from visual inspection of the space during the site visit. LDD is then selected from the curves in Figure 6.5.

The LLF factors e thru h are recoverable and can be improved upon by maintaining the room in its initial state. This means cleaning the walls and light fixtures through routine maintenance.

To calculate the total LLF value multiply factors a thru h together.

$$LLF = a \times b \times c \times d \times e \times f \times g \times h$$

STEP 7: Complete Calculations. Calculate the number of luminaires that are required to produce the desired luminous output using Eq. 6.4.

$$\text{No. Luminaires} = \frac{(\text{Footcandles})(L)(W)}{(\text{Lumens per luminaire})(CU)(LLF)} \quad (6.4)$$

Calculate the footcandle level produced using Eq. 6.5.

Footcandles =

$$\frac{(\text{No. Luminaires})(\text{Lumen per luminaire})(\text{CU})(\text{LLF})}{(\text{L})(\text{W})} \quad (6.5)$$

The Zonal Cavity Calculation would be done for each major room in the building. Hallways, closets, etc., do not require this analysis. After analyzing the total building, it is possible that some rooms can have light fixtures removed to reduce the energy consumption. Once it has been determined that the number of light fixtures in a room can be reduced, the critical decision is to decide which fixtures to remove. The lighting level at the task plane is the critical location. Therefore, light fixtures that directly light the work plane should be looked at closely before removing to insure the lighting levels at the task plane will not drop below the standards set in Table 6.3.

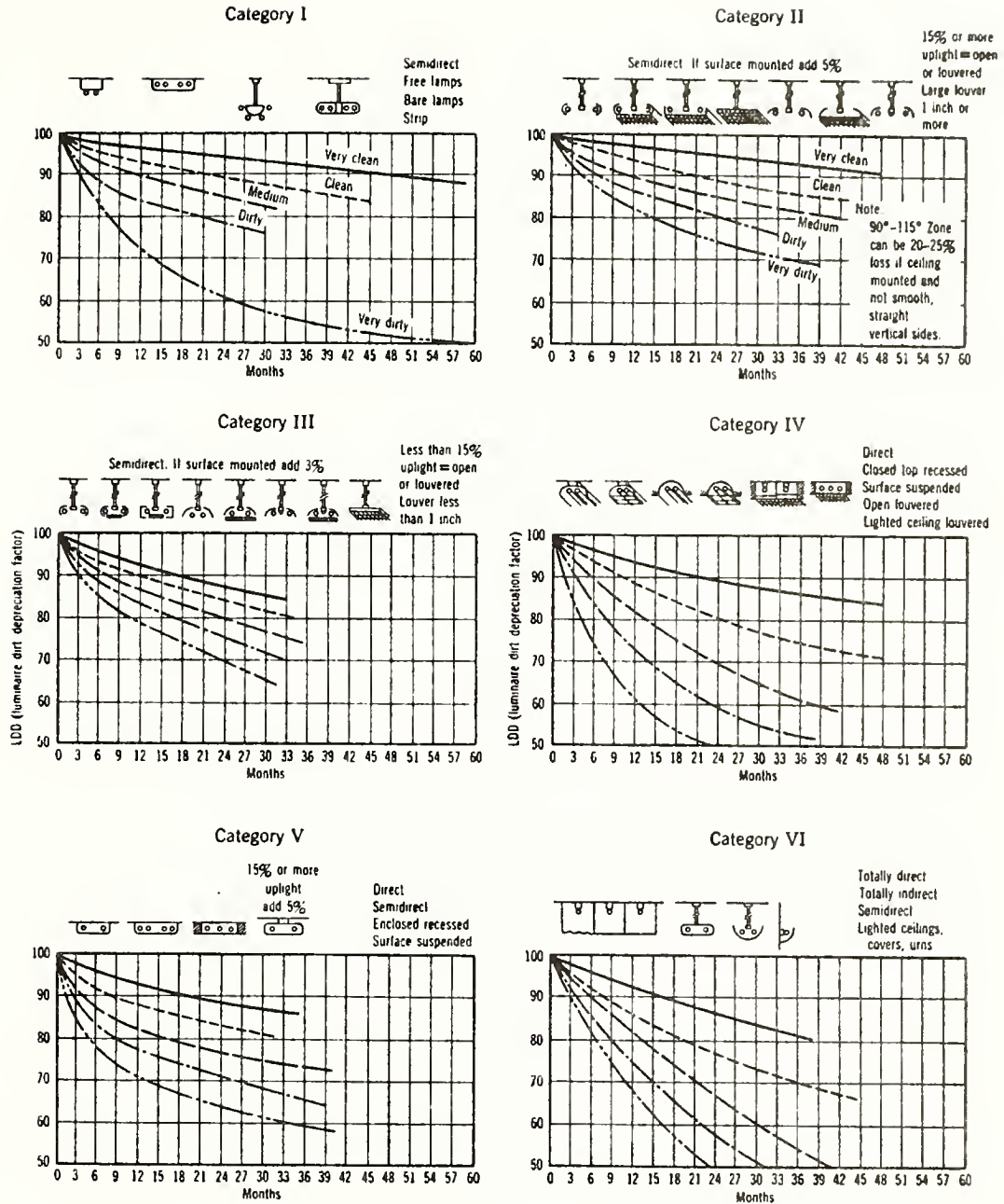


Figure 6.5 Luminaire Dirt Depreciation Factor (LDD) [6]

Table 6.5 Percent Effective Ceiling or Floor Cavity
Reflectance for Various Reflectance Combinations

Percent Ceiling or Floor Reflectance	90						80						70						50						30						10					
	90	70	50	30	80	70	50	30	80	70	50	30	70	50	30	70	50	30	70	50	30	65	50	30	10	50	30	10								
Ceiling or Floor Cavity Ratio	0	90	90	90	90	80	80	80	80	80	80	80	80	70	70	70	70	50	50	50	50	30	30	30	30	10	10	10	10							
	0.1	90	89	88	87	79	79	78	78	78	78	78	78	69	69	68	69	59	49	48	48	30	30	30	29	10	10	10	10							
	0.2	89	88	86	85	79	78	77	76	77	76	76	76	67	66	66	67	49	48	47	47	30	29	29	28	10	10	9	9							
	0.3	89	87	85	83	78	77	75	74	77	74	74	74	68	66	64	66	49	47	46	46	30	29	28	27	10	10	9	9							
	0.4	88	86	83	81	78	76	74	72	76	72	72	72	67	65	63	65	48	46	45	45	30	29	27	26	11	10	9	9							
	0.5	88	85	81	78	77	75	73	70	75	70	66	64	61	61	64	61	48	46	44	44	29	28	27	25	11	10	9	9							
	0.6	88	84	80	76	77	75	71	68	75	71	68	65	62	59	62	59	47	45	43	43	29	28	26	25	11	10	9	9							
	0.7	88	83	78	74	76	74	70	66	74	70	66	65	61	58	61	58	47	44	42	42	29	28	26	24	11	10	8	8							
	0.8	87	82	77	73	75	73	69	65	73	69	65	64	60	56	60	56	47	43	41	41	29	27	25	23	11	10	8	8							
	0.9	87	81	76	71	75	72	68	63	72	68	63	63	59	55	63	59	46	43	40	40	29	27	25	22	11	9	8	8							
	1.0	86	80	74	69	74	71	66	61	71	66	61	63	58	53	63	58	46	42	39	39	29	27	24	22	11	9	8	8							
1.1	86	79	73	67	74	71	65	60	71	65	60	62	57	52	62	57	46	41	38	38	29	26	24	21	11	9	8	8								
1.2	86	78	72	65	73	70	64	58	70	64	58	61	56	50	61	56	45	41	37	37	29	26	23	20	12	9	7	7								
1.3	85	78	70	64	73	69	63	57	73	69	63	57	61	55	61	55	45	40	36	36	29	26	23	20	12	9	7	7								
1.4	85	77	69	62	72	68	62	55	72	68	62	55	60	54	60	54	45	40	35	35	28	26	22	19	12	9	7	7								
1.5	85	76	68	61	72	68	61	54	72	68	61	54	59	53	61	53	44	39	34	34	28	25	22	18	12	9	7	7								
1.6	85	75	66	59	71	67	60	53	71	67	60	53	59	52	60	52	44	39	33	33	28	25	21	18	12	9	7	7								
1.7	84	74	65	58	71	66	59	52	71	66	59	52	58	51	66	51	44	38	32	32	28	25	21	17	12	9	7	7								
1.8	84	73	64	56	70	65	58	50	70	65	58	50	57	50	65	50	43	37	32	32	28	25	21	17	12	9	6	6								
1.9	84	73	63	55	70	65	57	49	70	65	57	49	57	49	65	49	42	37	31	31	28	25	20	16	12	9	6	6								
2.0	83	72	62	53	69	64	56	48	69	64	56	48	56	48	64	48	41	37	30	30	28	24	20	16	12	9	6	6								

Table 6.5 Continued

Ceiling or Floor Cavity Ratio		83	71	61	52	69	63	55	47	56	47	40	43	36	29	28	24	20	16	13	9	6
2.1		83	71	61	52	69	63	55	47	56	47	40	43	36	29	28	24	20	16	13	9	6
2.2		83	70	60	51	68	63	54	45	55	46	39	42	36	29	28	24	19	15	13	9	6
2.3		83	69	59	50	68	62	53	44	54	46	38	42	35	28	28	24	19	15	13	9	6
2.4		82	68	58	48	67	61	52	43	54	45	37	42	35	27	28	24	19	14	13	9	6
2.5		82	68	57	47	67	61	51	42	53	44	36	41	34	27	27	23	18	14	13	9	6
2.6		82	67	56	46	66	60	50	41	53	43	35	41	34	26	27	23	18	13	13	9	5
2.7		82	66	55	45	66	60	49	40	52	43	34	41	33	26	27	23	18	13	13	9	5
2.8		81	66	54	44	66	59	48	39	52	42	33	41	33	25	27	23	18	13	13	9	5
2.9		81	65	53	43	65	58	48	38	51	41	33	40	33	25	27	23	17	12	13	9	5
3.0		81	64	52	42	65	58	47	38	51	40	32	40	32	24	27	22	17	12	13	8	5
3.1		80	64	51	41	64	57	46	37	50	40	31	40	32	24	27	22	17	12	13	8	5
3.2		80	63	50	40	64	57	45	36	50	39	30	40	31	23	27	22	16	11	13	8	5
3.3		80	62	49	39	64	56	44	35	49	39	30	39	31	23	27	22	16	11	13	8	5
3.4		80	62	48	38	63	56	44	34	49	38	29	39	31	22	27	22	16	11	13	8	5
3.5		79	61	48	37	63	55	43	33	48	38	29	39	30	22	26	22	16	11	13	8	5
3.6		79	60	47	36	62	54	42	33	48	37	28	39	30	21	26	21	15	10	13	8	5
3.7		79	60	46	35	62	54	42	32	48	37	27	38	30	21	26	21	15	10	13	8	4
3.8		79	59	45	35	62	53	41	31	47	36	27	38	29	21	26	21	15	10	13	8	4
3.9		78	59	45	34	61	53	40	30	47	36	26	38	29	20	26	21	15	10	13	8	4
4.0		78	58	44	33	61	52	40	30	46	35	26	38	29	20	26	21	15	9	13	8	4
4.1		78	57	43	32	60	52	39	29	46	35	25	37	28	20	26	21	14	9	13	8	4
4.2		78	57	43	32	60	51	39	29	46	34	25	37	28	19	26	20	14	9	13	8	4
4.3		78	56	42	31	60	51	38	28	45	34	25	37	28	19	26	20	14	9	13	8	4
4.4		77	56	41	30	59	51	38	28	45	34	24	37	27	19	26	20	14	8	13	8	4
4.5		77	55	41	30	59	50	37	27	45	33	24	37	27	19	25	20	14	8	14	8	4
4.6		77	55	40	29	59	50	37	26	44	33	24	36	27	18	25	20	14	8	14	8	4
4.7		77	54	40	29	58	49	36	26	44	33	23	36	26	18	25	20	13	8	14	8	4
4.8		76	54	39	28	58	49	36	25	44	32	23	36	26	18	25	19	13	8	14	8	4
4.9		76	53	38	28	58	49	35	25	44	32	23	36	26	18	25	19	13	7	14	8	4
5.0		76	53	38	27	57	48	35	25	43	32	22	36	26	17	25	19	13	7	14	8	4

Table 6.6 Coefficients of Utilization for Typical Luminaires

To obtain a Coefficient of Utilization

1. Determine cavity ratios for the room, ceiling, and floor from Table 20.8
2. Determine the effective ceiling and floor cavity reflectances from Table 20.9. Use initial ceiling, floor, and wall reflectances
3. Obtain Coefficient of Utilization (CU) for 20% effective floor cavity reflectance from appropriate table below for luminaire type to be used. Interpolate, when necessary, to obtain CU for exact room cavity ratio for nearest effective ceiling cavity reflectances above and below reflectance obtained in Step 2; interpolate between these CUs to obtain CU for Step 2 ceiling cavity reflectance
4. If effective floor cavity reflectance differs significantly from 20%, obtain multiplier from Table 20.10 and apply this to the CU obtained in Step 3

NOTE: In some cases, luminaire data in this table are based on an actual typical luminaire, in other cases, the data represent a composite of generic luminaire types. Therefore, whenever possible, specific luminaire data should be used in preference to this table of typical luminaires.

The polar intensity sketch (candlepower distribution curve) and the corresponding spacing-to-mounting height guide are representative of many luminaires of each type shown. A specific luminaire may differ in perpendicular plane (crosswise) and parallel plane (lengthwise) intensity distributions and in S.M.H. guide from the values shown. However, the various coefficients depend only on the average intensity at each polar angle from nadir.

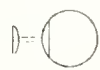
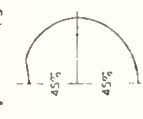
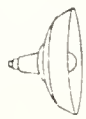
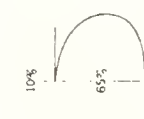
Typical Luminaire	Typical Distribution and Percent Lamp Lumens	Coefficients of Utilization for 20% Effective Floor Cavity Reflectance (R _{fc} = 20)										Coefficients of Utilization for 20% Effective Floor Cavity Reflectance (R _{fc} = 20)											
		RCR ^e					RCR ^e					RCR ^e					RCR ^e						
		0	1	2	3	4	5	6	7	8	9	10	0	1	2	3	4	5	6	7	8	9	10
1		V	15																				
3		IV	13																				

Table 6.6 Continued

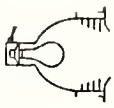
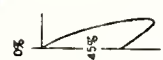
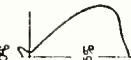
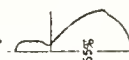
8		IV		0	53	53	53	52	52	49	49	47	47	45	45	44	04	
				1	51	50	49	50	49	48	47	47	46	45	44	43	04	
				2	48	47	46	48	46	45	45	44	44	43	43	42	03	
				3	47	45	44	46	45	44	44	43	43	42	41	41	03	
				4	45	43	42	44	43	42	42	41	41	40	40	40	03	
				5	43	41	40	43	41	40	39	38	37	36	35	34	03	
				6	42	40	39	41	40	38	37	36	35	34	33	32	03	
				7	40	38	37	40	38	37	36	35	34	33	32	31	03	
				8	39	37	36	38	37	36	35	34	33	32	31	30	03	
				9	37	36	34	37	35	34	33	32	31	30	29	28	03	
				10	36	34	33	36	34	33	32	31	30	29	28	27	03	
16	Reflector downlight with baffles and inside frosted lamp	III		0	92	92	92	90	90	86	86	82	82	79	79	77	16	
				1	85	82	80	83	81	79	78	76	75	74	73	72	16	
				2	77	73	70	75	72	69	68	66	64	63	62	61	16	
				3	70	65	61	68	64	60	58	56	54	52	51	50	16	
				4	63	58	53	62	57	53	50	48	46	44	43	42	16	
				5	57	51	47	56	51	47	44	42	40	38	37	36	16	
				6	51	45	41	51	45	41	38	36	34	32	31	30	16	
				7	46	40	35	45	39	35	32	30	28	26	25	24	16	
				8	41	35	31	41	35	31	28	26	24	22	21	20	16	
				9	37	31	27	37	31	27	24	22	20	18	17	16	16	
				10	33	27	24	33	27	23	20	18	16	15	14	13	16	
21	Wide-distribution ventilated reflector with clear HID lamp	II		0	84	84	84	80	80	82	82	75	75	69	69	66	21	
				1	85	82	80	82	79	77	75	73	72	69	68	66	21	
				2	76	72	66	74	70	66	63	61	58	55	53	51	21	
				3	69	63	59	66	61	57	54	51	48	45	43	41	21	
				4	62	56	51	60	54	50	47	44	41	38	36	34	21	
				5	55	49	44	53	48	43	40	36	33	31	30	29	21	
				6	50	43	39	48	42	38	34	30	26	23	21	20	21	
				7	45	38	34	43	37	33	29	25	21	18	16	15	21	
				8	40	34	29	39	33	29	24	20	16	13	11	10	21	
				9	36	30	25	35	29	25	20	16	13	11	10	9	21	
				10	33	26	22	32	26	22	18	14	11	9	8	7	21	
23	Diffuse aluminum reflector with 35°CW shielding	II		0	83	83	83	79	79	79	71	71	65	65	59	59	56	23
				1	75	72	70	72	69	68	65	64	62	59	58	56	23	
				2	67	63	60	65	61	58	57	54	51	48	45	43	23	
				3	61	56	52	58	54	51	48	45	42	39	37	36	23	
				4	55	49	45	53	48	44	41	38	35	32	30	29	23	
				5	49	44	40	47	42	39	36	33	30	27	25	24	23	
				6	45	39	35	43	38	34	30	26	22	19	18	17	23	
				7	40	35	31	39	34	30	26	22	18	15	14	13	23	
				8	36	31	27	35	30	26	22	18	14	11	10	9	23	
				9	33	27	23	32	26	23	19	15	11	8	7	6	23	
				10	30	24	21	29	24	20	16	12	8	5	4	3	23	

Table 6.6 Continued

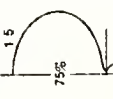
Typical Luminaire	Typical Distribution and Percent Lamp Lumens	Maint. Cat.	Maximum S/MH Guide ^a	RCR ^b	Coefficients of Utilization for 20% Effective Floor Cavity Reflectance ($\rho_{fc} = 20$)												WDR ^c					
					$\rho_{ce} = 0$				$\rho_{ce} = 10$				$\rho_{ce} = 30$									
					0	1	2	3	4	5	6	7	8	9	10	0						
28		VI	 75%  5%	0	77	77	77	67	67	67	49	49	49	33	33	33	16	16	16	11		
Luminous bottom suspended unit with extra-high-output lamp		V	Max. S/CH _{ap} = 1.5	1	87	64	62	59	57	54	44	42	41	30	29	28	17	16	16	10		
				2	59	54	50	51	48	45	38	36	34	26	25	23	15	14	13	09		
				3	51	46	42	45	41	37	34	31	28	23	21	20	13	12	12	07		
				4	45	40	35	40	35	31	30	27	24	20	18	17	12	11	10	06		
				5	40	34	30	35	30	27	26	23	20	18	16	14	10	09	08	05		
				6	36	30	26	32	27	23	24	20	18	16	14	12	09	08	07	05		
				7	32	26	22	28	23	20	21	18	15	15	12	11	08	07	06	04		
				8	29	23	19	25	21	17	19	16	13	13	11	09	08	06	06	03		
				9	26	20	17	23	18	15	17	14	12	12	10	08	07	06	05	03		
				10	24	18	15	21	16	13	16	12	10	11	09	07	06	05	04	03		
30				0	80	80	80	77	77	77	71	71	71	66	66	66	60	60	60	58		
Two-lamp prismatic wrap-around—multiply by 0.95 for four lamps		V	Max. S/CH _{ap} = 1.5	1	71	69	66	64	61	58	54	64	62	60	59	58	56	55	54	53	50	
				2	64	59	56	61	58	54	57	54	51	48	45	42	45	42	40	38	36	34
				3	57	52	48	55	50	47	51	48	45	42	39	37	34	31	28	26	24	23
				4	51	46	41	49	44	40	46	42	39	36	33	30	27	24	21	19	18	17
				5	46	40	36	44	39	35	41	37	34	31	28	25	22	19	17	16	15	14
				6	41	35	31	40	35	31	38	33	30	27	24	21	18	16	15	14	13	12
				7	37	31	27	36	31	27	34	29	26	23	20	17	15	14	13	12	11	10
				8	33	28	24	32	27	23	30	26	22	19	16	14	12	11	10	9	8	7
				9	30	24	20	29	24	20	27	23	19	16	14	12	11	10	9	8	7	6
				10	27	22	18	26	21	18	25	20	17	15	13	11	10	9	8	7	6	5
35				0	59	59	59	58	58	58	55	55	55	53	53	53	51	51	51	50		
Four-lamp, 2-ft-wide troffer with 45° plastic cover—multiply by 1.05 for two lamps and 0.95 for six lamps		IV	0%	1	54	52	50	52	51	49	50	49	48	47	46	45	44	43	42	41	40	
				2	48	45	43	47	44	42	45	43	41	44	42	40	42	41	39	39	38	37
				3	43	40	37	42	39	37	41	38	36	40	37	36	39	37	35	34	33	32
				4	39	35	32	38	35	32	37	34	32	36	33	31	35	33	31	30	29	28
				5	35	31	28	35	31	28	34	30	28	33	30	28	32	29	27	26	25	24
				6	32	28	25	32	28	25	31	27	25	30	27	25	29	26	24	23	22	21
				7	29	25	22	29	25	22	28	25	22	27	24	22	27	24	22	21	20	19
				8	26	22	20	26	22	20	25	22	20	25	22	19	24	21	19	18	17	16
				9	24	20	17	24	20	17	23	20	17	23	19	17	22	19	17	16	15	14
				10	22	18	16	22	18	16	21	18	16	21	18	16	21	18	17	16	15	14

Table 6.6 Continued

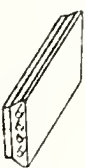
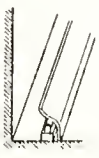
41		V	0° 5° 14° 12°	0	73	73	73	72	72	72	68	68	68	66	66	63	63	63	62	
	Fluorescent unit with flat prismatic lens, 4-lamp, 2 ft wide—multiply by 1.10 for 2-lamp			1	66	64	62	65	63	61	62	60	59	60	58	57	56	55	54	
				2	59	55	52	58	54	52	56	53	50	54	51	49	52	50	48	
				3	53	48	45	52	48	44	50	46	44	48	45	43	47	44	42	
				4	47	42	39	46	42	38	45	41	38	43	40	37	42	39	37	
				5	42	37	33	41	37	33	40	36	33	39	35	32	38	35	32	
				6	38	33	29	37	32	29	36	32	29	35	31	28	34	31	28	
				7	34	29	25	33	29	25	33	28	25	32	28	25	31	27	25	
				8	30	25	22	30	25	22	29	25	22	28	24	21	28	24	21	
				9	27	22	19	27	22	19	26	22	19	25	21	19	25	21	18	
				10	25	20	17	24	20	16	24	19	16	23	19	16	23	19	15	
45		Max. S.M.H. _{sp} = 1.2		1	42	40	39	36	35	33	25	24	23	Coves are not recommended for lighting areas having low reflectances						
				2	37	34	32	32	29	27	22	20	19							
				3	32	29	26	28	25	23	19	17	16							
				4	29	25	22	25	22	19	17	15	13							
				5	25	21	18	22	19	16	15	13	11							
				6	23	19	16	20	16	14	14	12	10							
				7	20	17	14	17	14	12	12	10	09							
				8	18	15	12	16	13	10	11	09	08							
				9	17	13	10	15	11	09	10	08	07							
				10	15	12	09	13	10	08	09	07	06							
48				1	p_{rc} from below ~45%															
				2																
				3																
				4																
				5																
				6																
				7																
				8																
				9																
				10																

Table 6.7 Factors for Effective Floor Cavity Reflectances Other Than 20%

For 30% effective floor cavity reflectance, *multiply* by appropriate factor below
 For 10% effective floor cavity reflectance, *divide* by appropriate factor below

Percent Effective Ceiling Cavity Reflectance, ρ_{cc}	80			70			50			10		
Percent Wall Reflectance, ρ_w	50	30	10	50	30	10	50	30	10	50	30	10
Room Cavity Ratio												
1	1.08	1.08	1.07	1.07	1.06	1.06	1.05	1.04	1.04	1.01	1.01	1.01
2	1.07	1.06	1.05	1.06	1.05	1.04	1.04	1.03	1.03	1.01	1.01	1.01
3	1.05	1.04	1.03	1.05	1.04	1.03	1.03	1.03	1.02	1.01	1.01	1.01
4	1.05	1.03	1.02	1.04	1.03	1.02	1.03	1.02	1.02	1.01	1.01	1.00
5	1.04	1.03	1.02	1.03	1.02	1.02	1.02	1.02	1.01	1.01	1.01	1.00
6	1.03	1.02	1.01	1.03	1.02	1.01	1.02	1.02	1.01	1.01	1.01	1.00
7	1.03	1.02	1.01	1.03	1.02	1.01	1.02	1.01	1.01	1.01	1.01	1.00
8	1.03	1.02	1.01	1.02	1.02	1.01	1.02	1.01	1.01	1.01	1.01	1.00
9	1.02	1.01	1.01	1.02	1.01	1.01	1.02	1.01	1.01	1.01	1.01	1.00
10	1.02	1.01	1.01	1.02	1.01	1.01	1.02	1.01	1.01	1.01	1.01	1.00

6.4.4 Zonal Cavity Calculation Example

Determine the lighting requirements for the conference room used in section 6.4.2 example and compare to the actual lighting system. The following information is known about the lighting system:

Illumination Range	75 fc
Area	540 sq ft
Ceill Height	9 ft
Fixture Height	9 ft
Lamp Abbreviation	F40T12CW
No. of Fixtures	15
Lamps per Fixture	4

SOLUTION

STEP 1: Determine the height of the three cavities, length and width of room, and cavity reflectances.

$$\text{Ceiling Cavity } h_{cc} = 0$$

$$\text{Room Cavity } h_{rc} = 9 - 2.5 = 6.5 \text{ ft}$$

$$\text{Floor Cavity } h_{fc} = 2.5 \text{ ft}$$

$$L = 30 \text{ ft}$$

$$W = 18 \text{ ft}$$

$$\text{Ceiling Reflectance} = 80\%$$

$$\text{Wall Reflectance} = 50\%$$

$$\text{Floor Reflectance} = 20\%$$

STEP 2: Calculate cavity ratios.

$$\text{RCR} = 5(6.5) \frac{30 + 18}{(30)(18)}$$

$$\text{RCR} = 2.89$$

$$\text{CCR} = 0 \text{ (surface mounted fixtures)}$$

$$\text{FCR} = 5(2.5) \frac{30 + 18}{(30)(18)}$$

$$\text{FCR} = 1.11$$

STEP 3: Obtain effective ceiling cavity reflectance.

Surface mounted fixtures therefore $\rho_{cc} = 80\%$.

STEP 4: Obtain effective floor cavity reflectance.

From Table 6.5:

percent floor reflectance	30	(20)	10
percent wall reflectance	50		50
1.1	26		11
FCR 1.11	26	x	y
1.2	26		12

In order to calculate the effective floor cavity reflectance will require two interpolations.

Interpolate between the FCR:

1.1	11
1.11	y
1.2	12

Solve for y:

$$y = (11-12) \frac{(1.11 - 1.2)}{(1.1 - 1.2)} + 12$$

$$y = 11.1$$

Interpolate between the Percent Floor Reflectances:

30	20	10
26	x	11.1

Solve for x:

$$x = (20 - 11.1) \frac{(20 - 10)}{(30 - 10)} + 11.1$$

$$x = 15.55 \quad \text{use } 16\%$$

STEP 5: Obtain coefficient of utilization (CU) from Table 6.6. The light fixture used in the conference room is similar to fixture 41 in Table 6.6.

From Table 6.6

$$\frac{\rho_{cc} \quad 80\%}{\rho_w \quad 50\%}$$

RCR

2	.59
2.89	x
3	.51

Interpolate to solve: CU = 0.52

STEP 6: Determine LLF.

Nonrecoverable = 0.9

Recoverable

Room Surface Dirt = 0.9

Lamp Lumen Depreciation = 0.85

Burnouts = 0.95

LDD (From Table 6.6 Type V
From Fig. 6.5 (24 Month) = 0.78

Calculate LLF:

$$\text{LLF} = 0.9 \times 0.9 \times 0.85 \times 0.95 \times 0.78$$

$$\text{LLF} = 0.51$$

STEP 7: Complete Calculations:

$$\text{No. Luminaires} = \frac{(75\text{fc}) \times (30) \times (18)}{(12,600) \times (0.52) \times (0.51)}$$

$$\text{No. of Luminaires} = 12.12 \quad \text{use 12 fixtures.}$$

$$\text{Footcandles} = \frac{(12) \times (12,600) \times (0.52) \times (0.51)}{(30) \times (18)}$$

$$\text{Footcandles} = 74.25$$

Figure 6.6 is Form 6.1 filled out for the above example illustrating the use of the form.

FORM 6.1 Zonal Cavity Calculation Form

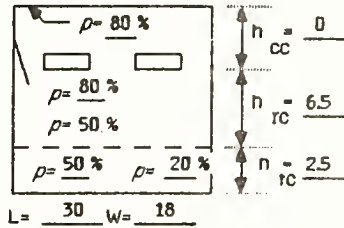
GENERAL INFORMATION	
Building and Room Identification <u>EXAMPLE</u>	
Average maintained illumination for design: <u>75</u> fc	Lamp Data:
Luminaire data:	Type and color: <u>F40T12CW</u>
Manufacture: _____	Number per luminaire: <u>4</u>
Catalog number: _____	Total lumens per luminaire: <u>12,600</u>

SELECTION OF COEFFICIENT OF UTILIZATION

STEP 1: Fill in sketch at right.

STEP 2: Determine Cavity Ratios by formulas.

$$\begin{aligned}\text{Room Cavity Ratio, RCR} &= \frac{2.89}{\text{Ceiling Cavity Ratio, CCR} = 0} \\ \text{Floor Cavity Ratio, FCR} &= \frac{1.11}\end{aligned}$$

STEP 3: Obtain effective ceiling cavity reflectance (ρ_{cc}) from Table 6.5.

$$\rho_{cc} = \frac{80}{}$$

STEP 4: Obtain effective floor cavity reflectance (ρ_{fc}) from Table 6.5.

$$\rho_{fc} = \frac{16}{}$$

STEP 5: Obtain coefficient of utilization (CU) from Table 6.6.

$$CU = \frac{25}{}$$

SELECTION OF LIGHT LOSS FACTORS

STEP 6: Determine Light Loss Factors

Unrecoverable		Recoverable	
Luminaire ambient temperature	_____	Room surface dirt depreciation	<u>0.9</u>
Voltage to luminaire	_____	Lamp lumen depreciation	<u>0.85</u>
Ballast factor	<u>0.9</u>	Lamp burnouts factor	<u>0.95</u>
Luminaire surface depreciation	_____	Luminaire dirt depreciation LDD	<u>0.78</u>

$$\text{Total light loss factor, LLF (product of individual factors above): } \underline{0.51}$$

CALCULATIONS

STEP 7: Complete Calculations as follows:

(Average Maintained Illumination Level)

$$\begin{aligned}\text{Number of luminaires} &= \frac{(\text{footcandles}) \times (\text{Area in square feet})}{(\text{Lumens per luminaire}) \times (CU) \times (LLF)} \quad (\text{Eq. 6.4}) \\ &= \frac{(75 \text{ fc}) \times (30) \times (18)}{(12,600) \times (0.52) \times (0.51)} = \underline{12.12 \text{ use 12 fixtures}}\end{aligned}$$

$$\begin{aligned}\text{Footcandles} &= \frac{(\text{Number of luminaires}) \times (\text{Lumens per luminaire}) \times (CU) \times (LLF)}{(\text{Room Area, } L \times W, \text{ in sq ft})} \quad (\text{Eq. 6.5}) \\ &= \frac{(12) \times (12,600) \times (0.52) \times (0.51)}{(30) \times (18)} = \underline{74.25 \text{ fc}}\end{aligned}$$

Calculated by: _____ Date: _____

Figure 6.6 Form 6.1 Zonal Cavity Example

The next step after completing the Zonal Cavity Calculations is to compare the calculated values with the actual. The results of the field study indicated that the conference room had a total of 15 fixtures with an average illumination value of 82.5 fc. Therefore, it can be concluded that approximately 3 fixtures can be removed from the conference room without reducing the illumination value for the room below the requirements. The important decision is to determine which fixtures to disconnect. If the room has a conference table in the center, then it would probably be best to disconnect three fixtures along the walls. It would not be necessary to totally remove the fixtures, but only to disconnect the lamps and ballast in each fixture. It is important when removing lamps from a fixture to also disconnect the ballast. Ballast will still continue to consume power even after the lamps are taken out.

CHAPTER 7 ENERGY CONSUMPTION SURVEY

7.1 Introduction

An energy consumption survey is the accounting of actual energy used to operate a building. By obtaining utility bills for the building being audited actual energy consumption can be determined. An effective way of stating energy consumption is in terms of BTU per gross conditioned square foot per year, (or month). This is referred to as the Energy Utilization Index, (EUI).

$$EUI = \frac{BTU}{(Gross\ Conditioned\ Area)(Year)} \quad (7.1)$$

where:

EUI- is the Energy Utilization Index.

Gross Cond. Area- is the area of the building that is heated and cooled, sq ft.

Year- is the time period of the EUI.

The energy consumption survey is broken into two periods. The first period is the base year energy consumption. This covers the year of energy consumption prior to implementing any energy conservation opportunities, ECO's.

The base year EUI indicates the amount of energy used by the building in its present state. The second period starts after the ECO's have been implemented. By comparing the two EUI's, the performance of the building after implementing the ECO's can be evaluated. The second period can last for several years depending upon the State's needs. A period of two to three years is recommended for an evaluation period.

Several advantages arise from developing EUIs. First, a comparison of the base year energy consumption to the energy consumption after implementing ECO's will give some indication of the ECOs' success in reducing energy consumption. Second, the data collected for calculating an EUI will enable the energy auditor to determine how well he calculated the theoretical energy consumption for the building during the heating season. Third, by calculating an EUI for each year after implementing the ECOs, conditions leading to energy waste may be noticed by watching for drastic movements in the EUI from year to year.

7.2 Required Material for Completing the Energy Consumption Survey

A. Form 7.1 Energy Management Form, see Appendix B

B. Energy consumption data depending upon the energy source used:

1. ELECTRICITY: The monthly electric bills for one full year.
2. FUEL OIL:
 - i. To calculate the monthly consumption the amount of fuel oil in the tank in the beginning and end of the month and the quantity in gallons of each delivery made during that month is needed;
 - ii. The price per gallon of the oil in dollars per gallon;
 - iii. The type of fuel used - #2, #4, #5 or #6.
3. NATURAL GAS:
 - i. The monthly bills for the same full year;
 - ii. The heat content (the number of BTU per cubic foot) of the gas if available. If it is not available, use 1030 BTU per cubic foot.
4. STEAM: If steam is purchased, the monthly bills for the same full year, the quantity used and the heat content of the steam for each pound or cubic foot purchased are needed.
5. If any other type of fuel (coal, wood, etc.) is

used, the monthly consumption, the cost per unit, and the heat content of the fuel per unit is needed.

6. From the local utility or weather station obtain the monthly total heating degree days and cooling degree days for the location of the building being audited during the same year.

7.3 Procedures for Calculating the EUI

Form 7.1, see Figure 7.1, is provided to enable the EUI to be calculated in a straight forward manner. The following instructions explain the steps to take in using the form [8].

STEP 1: Enter the monthly heating degree days in column 2 and the monthly cooling degree days in column 3.

STEP 2: Follow the instructions below for the fuel(s) used in the building.

A. ELECTRICITY - CONSUMPTION AND COST:

1. For each monthly electric bill covered by the majority of the billing period, (The billing period may vary from 25 to 40 days. If so, adjust it to be consistent

with the other energy billing periods on the form.) calculate the Kilowatt-hours (kWh) per day and multiply by the number of days in the month or period being used for oil and gas, etc.:

- a. enter in column 4 the total number of kWh used during the month;
 - b. enter in column 5 the total cost for the month that appears on the bill;
 - c. to calculate column 6, the cost per kilowatt hour (kWh), divide column 5 by column 4;
 - d. to calculate the cost per million BTU (\$/MMBTU) multiply column 6 by 293 and enter this in column 7.
2. After completing each month, calculate the annual totals and averages.
- a. sum column 4 and enter at the bottom of the column;
 - b. sum column 5 and enter at the bottom of the column;
 - c. divide the sum of column 5 by the sum of column 4 and enter in the

annual average at the bottom of column 6;

d. multiply the annual average of column 6 by 293 and enter at the bottom of column 7.

B. OIL - CONSUMPTION AND COST:

1. Enter in column 8 the oil consumption in gallons for each month.

2. Enter the price per gallon in column 9 in dollars per gallon. For example, if it is \$1.25 per gallon, enter 1.25.

3. Calculate the total per month and enter in column 10. Multiply column 9 by column 8.

4. To calculate the cost per million BTU (column 11), divide column 9 by the conversion factor for the fuel listed as follows:

No. 2 oil - divide by .139 MMBTU/gal.

No. 4 oil - divide by .150 MMBTU/gal.

No. 5 oil - divide by .152 MMBTU/gal.

No. 6 oil - divide by .153 MMBTU/gal.

5. Calculate the annual total and averages:

1. sum column 8;
2. sum column 10;
3. divide column 10 by column 8 and enter at the bottom of column 9;
4. divide column 9 by conversion factor above (B4.) and enter at the bottom of column 11.

C. NATURAL GAS - CONSUMPTION AND COST:

1. Enter in column 12 the consumption for each month in 1000 cubic feet (MCF). If the bill is not in MCF, use the following formulas to convert:

- a. if the bill is in CCF (100 cubic feet) divide the total by 10:

$$\underline{\hspace{2cm}} \text{CCF} / 10 = \underline{\hspace{2cm}} \text{MCF};$$

- b. if the bill is in CF (cubic feet) divide the total by 1000:

$$\underline{\hspace{2cm}} \text{CF} / 1000 = \underline{\hspace{2cm}} \text{MCF},$$

- c. if the bill is in therms, divide the total by 10.30 (This figure is based on the 1977 national average of 1030 BTU per cubic foot. If the the actual heat content of the gas

is known, such as 1040, adjust accordingly , i.e., 10.40.)

_____therms / 10.30 = _____MCF.

2. Enter the total cost for each month in column 13.
3. To calculate column 14, the cost per MCF, divide column 13 by column 12.
4. To calculate column 15, the cost per million BTU, divide column 14 by 1.030. Or, if the heat content of the particular gas is known: column 14 divided by heat content per cubic foot times 1000 = column 15.
5. Calculate the annual totals and averages:
6. sum column 12;
7. sum column 13;
8. divide column 13 by column 12 and enter in the bottom of column 14;
9. calculate the average of column 15 by using one of the following:
 - divide column 14 by 1.030

or

- divide column 14 by the heat content per cubic foot and multiply by 1000.

D. If the building uses any other type of fuel or energy, use the same basic procedures with the goal of arriving at the cost per million BTU (MMBTU). Other sheets may need to be set up for other types of fuel.

STEP 3: Determine the monthly total and yearly total energy cost in column 20.

A. Column 20 is the monthly total energy cost. Sum the monthly total cost for each type of energy used. For example, if the building used electricity, oil, and gas in February, add the entries in column 5, column 10, and column 13 and enter the sum in column 20.

After each month has been completed, sum up column 20 to calculate the energy cost for the year. Enter the total at the bottom of column 20.

STEP 4: Determine the annual energy consumption.

Annual energy consumption is determined easily by multiplying the total annual amount of a given energy form (Columns 4,8,12, and 16) by the appropriate conversion factor. The result in each

case is the BTU equivalent of energy consumed. Add together to determine total BTU consumed for the year.

STEP 5: Calculate the EUI.

Energy utilization index (BTU per gross conditioned square foot per year) is determined easily by dividing the total annual energy consumption in BTU consumed by the total gross conditioned square footage of the building.

FORM 7.1 ENERGY MANAGEMENT FORM

BUILDING _____

YEAR _____

MONTH	HEATING DEGREE DAYS	COOLING DEGREE DAYS	ELECTRICITY				OIL				NATURAL GAS				COAL MOU —		TOTAL ENERGY COST		
			QUANTITY KWH	COST (DOLLARS)		QUANTITY GALLONS	COST (DOLLARS)		QUANTITY MCF	COST (DOLLARS)		QUANTITY UNIT	COST (DOLLARS)						
			TOTAL \$	\$/KWH	\$/MMBTU	TOTAL \$	\$/GAL.	TOTAL \$	\$/MMBTU	TOTAL \$	\$/MCF	TOTAL \$	\$/MMBTU	TOTAL \$	\$/UNIT	\$/MMBTU			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
JAN.																			
FEB.																			
MAR.																			
APR.																			
MAY																			
JUN.																			
JUL																			
AUG.																			
SEP.																			
OCT.																			
NOV.																			
DEC.																			
ANNUAL TOTAL \$			A				B				C				D				
ANNUAL AVERAGES																			

BUILDING DATA		ANNUAL ENERGY CONSUMPTION IN BTU				CONVERSION FAC.	BTU/YEAR	ENERGY UTILIZATION INDEX	
GROSS CONDITIONED AREA (SQ FT)		QUANTITY	KWH	X		X-413		TOTAL ENERGY CONSUMPTION BTU/YR	
GEN. NOTES:		A	ELECTRICITY					EUI = $\frac{\text{TOTAL ENERGY CONSUMPTION BTU/YR}}{\text{GROSS CONDITIONED AREA (SQ FT)}}$	
		B	OIL					EUI = $\frac{\text{BTU/FT}^2 \text{ /YR}}{\text{BTU/FT}^2 \text{ /YR}}$	
		C	NATURAL GAS					EUI = $\frac{\text{BTU/FT}^2 \text{ /YR}}{\text{BTU/FT}^2 \text{ /YR}}$	
		D	OTHER FUEL					EUI = $\frac{\text{BTU/FT}^2 \text{ /YR}}{\text{BTU/FT}^2 \text{ /YR}}$	
		TOTAL =							

Figure 7.1 Form 7.1 Energy Management Form

7.4 EUI Example

Calculate an EUI for a district office building located in Fort Wayne, Indiana. The required utility information is shown in Figure 7.2. As can be seen from Fig. 7.2, this office is heated during the winter with natural gas and cooled during the summer with electricity.

The building is two stories with approximately 4,848 sq ft per floor. The entire two floors are heated and cooled; therefore, the gross conditioned floor area is 9,696 sq ft.

The calculations are shown on Form 7.1 in Fig. 7.3. Follow along with the instructions above and calculate the EUI in Fig. 7.3. The procedure is straight forward.

Natural Gas Usage

Billing Period	Amount Paid dollars	CCF Used (100 CF)
1/5/83-2/6/83	2781	5,733
2/6/83-3/7/83	2743	5,627
3/7/83-4/6/83	2581	4,977
4/6/83-5/5/83	1590	3,044
5/5/83-6/6/83	577	1,114
6/6/83-7/6/83	161	307
7/6/83-8/4/83	118	223
8/4/83-9/2/83	106	201
9/2/83-10/4/83	289	612
10/4/83-11/4/83	905	1,973
11/3/83-12/5/83	2086	4,674
12/5/83-1/5/84	3605	8,080
	-----	-----
Total	17541	36,565

Electrical Usage

Billing Period	Amount Paid dollars	kWh Used
1/10/83-2/8/83	1304	25,320
2/8/83-2/8/83	1593	33,720
3/10/83-4/11/83	1264	27,600
4/11/83-5/10/83	1145	23,880
5/10/83-6/9/83	1167	24,000
6/9/83-7/11/83	1873	37,920
7/11/83-8/9/83	2047	42,000
8/9/83-9/8/83	1936	39,120
9/8/83-10/7/83	1456	28,440
10/7/83-11/7/83	1162	25,200
11/7/83-12/8/83	1378	27,360
12/8/83-1/10/84	1859	34,920
	-----	-----
Total	17,742	369,480

Figure 7.2 Utility Data for EUI Example

FORM 7.1 ENERGY MANAGEMENT FORM

BUILDING Fort Wayne District Office

YEAR

1983

MONTH	HEATING DEGREE DAYS	COOLING DEGREE DAYS	ELECTRICITY				OIL				NATURAL GAS				COAL QUANTITY UNIT	PURCHASED STEAM -- OTHER	TOTAL ENERGY COST		
			QUANTITY		COST (DOLLARS)		QUANTITY		COST (DOLLARS)		QUANTITY		COST (DOLLARS)						
			KTWH	\$/KTWH	TOTAL \$	\$/KTWH	CALLONS	\$/CALL	TOTAL \$	\$/CALL	RCF	\$/RCF	TOTAL \$	\$/RCF					
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
JAN.	1405	-	25320	1304	.051	14.94					573.3	2781	4.85	4.71					4085
FEB.	908	-	33720	1593	.047	13.77					562.7	2703	4.87	4.73					4336
MAR.	1125	-	27600	1264	.046	13.08					497.7	2580	5.18	5.03					3944
APR.	524	4	23880	1145	.048	14.06					304.4	1590	5.22	5.07					2735
MAY	272	10	24000	1167	.049	14.36					111.4	577	5.18	5.03					1744
JUN.	-	241	37920	1873	.049	14.36					30.7	161	5.24	5.09					2034
JUL.	-	436	42000	2047	.049	14.36					22.3	118	5.29	5.14					2165
AUG.	-	418	39120	1936	.049	14.36					20.1	106	5.27	5.12					2042
SEP.	78	168	28440	1456	.051	14.94					61.2	289	4.72	4.58					1745
OCT.	310	16	25200	1162	.046	13.48					197.3	905	4.59	4.56					2057
NOV.	596	-	27360	1378	.050	14.65					467.4	2086	4.46	4.35					3464
DEC.	1352	-	30920	1859	.053	15.53					808.0	3605	4.46	4.33					5464
ANNUAL TOTALS	6571	1293	369480	17702			8				3656.5	17541			0				35,725
ANNUAL AVERAGES						.049	14.36						4.80	4.66					

BUILDING DATA		ANNUAL ENERGY CONSUMPTION IN BTU		CONVERSION FAC.		ENERGY UTILIZATION INDEX	
CROSS CONDITIONED AREA (SQ FT)	9696	QUANTITY 24-0000	\$/BTU	QUANTITY 3413	\$/BTU	TOTAL ENERGY CONSUMPTION BTU/YR	CROSS CONDITIONED AREA (SQ FT)
GEN. NOTES: This is a 2 story concrete tilt-up building. The south curtain wall is 90% single pane glass. This building is a District Office Building.	A	ELECTRICITY	KTWH	X	1,261 x 10 ⁶	EUI = $\frac{\text{TOTAL ENERGY CONSUMPTION BTU/YR}}{\text{CROSS CONDITIONED AREA (SQ FT)}}$ EUI = $\frac{5,027 \times 10^6}{9696}$ EUI = $\frac{518,461}{\text{BTU/FT}^2 \text{ YR}}$	EUI = $\frac{518,461}{\text{BTU/FT}^2 \text{ YR}}$
	B	OIL	CALLONS	X	3,656 x 10 ⁶		
	C	NATURAL GAS	RCF	X	3,766 x 10 ⁶		
	D	OTHER FUEL	X				
TOTAL		TOTAL		TOTAL			

Figure 7.3 EUI Calculation Example

CHAPTER 8 ENERGY CONSERVATION OPPORTUNITY ANALYSIS

8.1 Introduction

The goal of an energy conservation analysis is to improve the energy efficiency of the building in a cost effective manner. As discussed earlier in Chapter 4, there are two types of energy conservation opportunities, ECO's. The noncapital ECOs require little if any monetary expense and the capital ECOs require a substantial monetary expense. The noncapital ECOs were covered in Chapter 4. The purpose of this chapter is to explain the procedures for evaluating capital ECOs. Capital ECOs can range from adding insulation, replacing windows, to modifying lighting systems, etc.

When implementing a capital ECO there is a cost associated with its installation. For example, adding additional insulation to an exterior wall requires cost for material and labor to install the insulation. However, adding the additional insulation will improve the thermal characteristics of the building resulting in utility cost savings. This savings will offset the installation cost over a period of time. The time it takes for the savings to pay

for the installation cost is referred to as the Simple Payback Period, SPP. The time, usually measured in years, that it takes for the savings to pay for the installation cost defines the payback period.

There may be several alternatives available. For example, the exterior wall could have 2,4,6 or 8 inches of insulation added. Each alternative would be more expensive due to the additional cost for the material and would result in a different payback period for each alternative. By calculating the payback period for each thickness the optimal one can be selected.

When evaluating potential capital ECOs, they must be evaluated by item. For example, adding insulation would be one item and replacing the windows would be another item. Within each item there would be several alternatives. Once the best alternative has been selected from each item, then the items can be ranked according to payback period and the optimal mix of items selected.

The first step in evaluating capital ECOs is to generate a list of possible ECO items. In concept, a capital ECO is an addition or replacement of a building component or system that will improve the energy efficiency of the building. The energy auditor will have to determine what capital ECOs might work for a particular building. This will have to be based on his/her experience and knowledge of possible

energy conservation measures. Later in the chapter results are presented from the previous study [1] that will show what types of capital ECOs have been determined to meet the payback period criteria for the State. This information will help the energy auditor in selecting possible capital ECOs.

Once the list of possible capital ECO items has been determined, the next step is to determine the cost of each alternative. The cost must be calculated for each alternative within each item and should include any cost associated with installing or implementing the alternative. These costs can include removing the existing component or system, material and labor costs to install the component or system, and the cost to operate the component or system. Costs for material and labor can be determined from subcontractors, vendors and in-house cost records if available. Operating costs can be determined from suppliers or manufactures.

After the cost for each alternative has been determined, each alternative is evaluated by calculating the SPP. The procedure for calculating the SPP is presented in section 8.3

8.2 Required Material to Complete ECO Analysis

- * Completed heat loss and lighting calculations
- * Forms 8.1 and 8.2, see Appendix A
- * Calculator

8.3 Procedure for Completing ECO Analysis

Forms 8.1 and Form 8.2 are provided to enable the different capital ECOs to be evaluated in a systematic manner, see Figures 8.1 and 8.2. The following instructions explain the steps to take in using the forms, followed by an illustrative example to help clarify the process.

8.3.1 Instructions for Form 8.1

STEP 1: Fill out the top portion of the Form.

STEP 2: Enter the input data for the current system and each alternative being analyzed. The entries are as follows:

IC - Initial cost is the cost of installing the ECO. Form 8.2 is a typical estimating form used to estimate construction costs. The costs that must be determined include any cost associated with

removing the existing system, and any cost for material and labor to install the system. Equipment is included as a material item in the estimate.

FC - Fuel consumption is the amount of fuel in units per year, i.e., gals/yr, for the current system and each alternative. It is hoped that the alternative will consume less fuel than the original system. This is where the major cost savings should occur. The Modified Degree Day Formula, Eq. 5.19 in Chapter 5, is used to determine the annual fuel consumption.

FP - Projected Average Fuel Price is the expected price in dollars per unit for the fuel.

AOC - Annual Operating Costs are any expenses required to operate or maintain the current system or proposed alternative after it has been installed.

STEP 3 After the Input data has been determined and entered on Form 8.1, the next step is to calculate the Simple Payback Period as follows:

Calculate the Annual Fuel Cost (AFC) for the current system and each alternative by multiplying

their respective Fuel Consumption (FC) and Fuel Price (FP).

$$AFC = FC \times FP$$

Calculate the Annual Fuel Savings (AFS) that each alternative will have over the current system by subtracting the Annual Fuel Cost of each alternative (AFC_a) from the Annual Fuel Cost of the current system (AFC_c). If this number is negative then there is no fuel savings.

$$AFS = AFC_c - AFC_a$$

Calculate the Annual Costs (AC) of operating the current system and each proposed alternative by adding the Annual Fuel Cost (AFC) and the Annual Operating Cost (AOC).

$$AC = AFC + AOC$$

Calculate the Annual Cost Savings (ACS) for each alternative by subtracting the Annual Cost of the alternative (AC_a) from the Annual Cost of the current system (AC_c).

$$ACS = AC_c - AC_a$$

Calculate the Simple Payback Period (SPP) for each alternative by dividing the Initial Cost (IC) of

the alternative by the Annual Cost Savings (ACS) of the alternative.

$$SPP = \frac{IC}{ACS}$$

After the Simple Payback Period has been calculated for each alternative, the alternatives can be ranked according to their SPP. Only one alternative per item can be selected. For example, if the item was adding insulation of 2,4,6 or 8 inches only one thickness would be selected.

FORM 8.1 POTENTIAL ENERGY CONSERVATION OPPORTUNITIES
SIMPLE PAYBACK ANALYSIS FORM

Item _____ Date _____

STEP 1

Description _____

Input Data	STEP 2	Label	Item	Current System	Alternative No. 1	Alternative No. 2	Alternative No. 3
		IC	Initial Costs (\$)				
		FC	Fuel consumption (units/yr)				
		FP	Projected Average Fuel Price (\$/Unit)				
		AOC	Annual Operating Costs (\$/yr)				
	STEP 3	AFC	Annual Fuel Costs = $FC \times FP$ (\$/yr)				
		AFS	Annual Fuel Savings = $AFC_C - AFC_A$ (\$/yr)				
		AC	Annual Costs = $AFC + AOC$				
		ACS	Annual Cost Saving = $AC_C - AC_A$ (\$/yr)				
		SPP	Simple Payback Period = IC / ACS (\$/yr)				

Figure 8.1 Form 8.1 Potential Energy Conservation Opportunities Simple Payback Analysis Form

[illegible]

Figure 8.2 Form 8.2 Estimate Work Sheet

8.3.2 Energy Conservation Opportunity Analysis Example

The example building in Chapter 3 does not have any insulation in the roof and the walls at the gabled ends, see Figures 3.6 and 3.7. Calculate the simple payback period for the following three alternatives.

Alternative No. 1	Add 6 inches of insulation to the roof.
Alternative No. 2	Add 3.5 inches of insulation in the wall and roof.
Alternative No. 3	Add 3.5 inches of insulation to the wall and 6 inches to the roof.

Existing conditions:

Wall (gable end)	Area	262	U = 0.323
Roof	Area	2350	U = 0.2253

$$q_{t, \text{wall and roof}}: 5670 + 35,473 = 41,143 \text{ BTU/hr}$$

Fuel: Natural Gas
Heating Degree Days: 5500

CALCULATIONS

Figure 8.4 is Form 8.1 filled out with the appropriate entries. The calculations in Figure 8.4 are explained below.

STEP 2: Input Data

IC- see Figure 8.3. The costs for the alternatives were determined from the Means Manual [9] and are

for example only. True costs should be determined from subcontractors, local vendors, or in-house cost data.

FC- The fuel consumption is calculated using the modified degree day formula for the current system and the three alternatives.

FC Current System

$$FC = \frac{q_t \times D \times 24 \times C_d}{TD \times n \times V} \quad (5.19)$$

$$FC = \frac{(41,143 \text{ Btu/hr})(5500)(24)(0.60)}{(67^\circ \text{F})(0.55)(104,000 \text{ BTU/CCF})}$$

$$FC = 850 \text{ CCF}$$

FC Alternative No. 1. Calculate the new U value for the roof after adding 6 inches of insulation:

$$U_{\text{roof}} = 0.0511$$

Calculate the new heat loss rate:

$$\begin{aligned} q_{\text{roof}} &= (0.0511)(2350)(67) = 8,045 \text{ BTU/hr} \\ q_{\text{wall}} &= 5,670 \text{ BTU/hr} \\ q_t &= \overline{13,715 \text{ BTU/hr}} \end{aligned}$$

Calculate the new fuel consumption, FC:

$$FC = \frac{(13,715 \text{ Btu/hr})(5500)(24)(0.60)}{(67^\circ \text{F})(0.55)(104,000 \text{ BTU/CCF})}$$

$$FC = 283 \text{ CCF}$$

FORM 8.1 POTENTIAL ENERGY CONSERVATION OPPORTUNITIES
SIMPLE PAYBACK ANALYSIS FORM

Item Add Insulation to roof and end wall Date _____

STEP 1

Description The roof and end walls above the ceiling line do not have insulation.
To add insulation to the end walls will require removing existing sheetrock, adding
insulation, and replacing new sheetrock. To add insulation to the roof will not require
any demolition.

I n p u t D a t a	S T E P 2	Label	Item	Current System	Alternative No. 1	Alternative No. 2	Alternative No. 3
		IC	Initial Costs (\$)		1283	1148	1544
		FC	Fuel consumption (units/yr)	850	283	286	197
		FP	Projected Average Fuel Price (\$/Unit)	0.60	0.60	0.60	0.60
		AOC	Annual Operating Costs (\$/yr)	0	0	0	0
C a l c u l a t i o n s	S T E P 3	AFC	Annual Fuel Costs = $FC \times FP$ (\$/yr)	510	169	172	118
		AFS	Annual Fuel Savings = $AFC_C - AFC_A$ (\$/yr)		341	338	392
		AC	Annual Costs = $AFC + AOC$	510	341	338	392
		ACS	Annual Cost Saving = $AC_C - AC_A$ (\$/yr)		341	338	392
		SPP	Simple Payback Period = IC / ACS (\$/yr)		3.76	3.39	3.94

Figure 8.3 Form 8.1 Potential Energy Conservation Opportunities Simple Payback Analysis Form Example

FORM 8.2 ESTIMATE WORK SHEET								
PROJECT		EXAMPLE BUILDING			ESTIMATE NO. _____			
LOCATION		_____			SHEET NO. <u>1</u>			
_____		_____			DATE _____			
SUMMARY BY		CHECKED BY						
DESCRIPTION	QUANTITY	UNIT	MAT'L	LAB.	MATERIAL	LABOR	SUB CONTRACT	TOTAL
ALTERNATIVE No. 1								
Install 6 inch Insulation overhead & profit	2350	sf	.30	.12	705	282		987
								296
Total								1283
ALTERNATIVE No. 2								
Remove sheetrock	262	sf	-	.17		44		44
Add wall Insulation 3.5 in.	262	sf	.18	.11	47	29		76
Add roof Insulation 3.5 in.	2350	sf	.18	.11	423	259		682
Replace sheetrock	262	sf	.15	.16	39	42		81
Overhead & Profit								265
Total								1148
ALTERNATIVE No. 3								
Remove sheetrock	262	sf	-	.17		44		44
Add wall Insulation 3.5 in.	262	sf	.18	.11	47	29		76
Add roof Insulation 6.0 in.	2350	sf	.30	.12	705	282		987
Replace sheetrock	262	sf	.15	.16	39	42		81
Overhead & Profit								365
Total								1544

Figure 8.4 Form 8.2 Estimate Work Sheet for ECO Example

FC Alternative No. 2. Calculate the new U value for the roof and wall after adding 3.5 inches of insulation:

$$U_{\text{roof}} = 0.0783$$

$$U_{\text{wall}} = 0.0855$$

Calculate the new heat loss rate:

$$q_{\text{roof}} = (0.0783)(2350)(67) = 12,328 \text{ BTU/hr}$$

$$q_{\text{wall}} = (0.0855)(262)(67) = 1,501 \text{ BTU/hr}$$

$$q_t = \overline{13,829 \text{ BTU/hr}}$$

Calculate the new fuel consumption, FC:

$$FC = \frac{(13,829 \text{ Btu/hr})(5500)(24)(0.60)}{(67^\circ \text{F})(0.55)(104,000 \text{ BTU/CCF})}$$

$$FC = 286 \text{ CCF}$$

Alternative No. 3.

Calculate the new U value for the roof and wall after adding 3.5 inches of insulation:

$$U_{\text{roof}} = 0.0511$$

$$U_{\text{wall}} = 0.0855$$

Calculate the new heat loss rate:

$$q_{\text{roof}} = (0.0511)(2350)(67) = 8,045 \text{ BTU/hr}$$

$$q_{\text{wall}} = (0.0855)(262)(67) = 1,501 \text{ BTU/hr}$$

$$q_t = \overline{9,546 \text{ BTU/hr}}$$

Calculate the new fuel consumption, FC:

$$FC = \frac{(9,546 \text{ Btu/hr})(5500)(24)(0.60)}{(67^\circ \text{F})(0.55)(104,000 \text{ BTU/CCF})}$$

$$FC = 197 \text{ CCF}$$

Determine projected average fuel price, FP. The FP can be obtained from local utility companies and should be updated accordingly.

Annual operating cost for adding insulation is zero. After the insulation is added there is no additional cost to maintain it.

STEP 3: Calculations

AFC

Current System

Annual Fuel Costs = FC x FP
 Annual Fuel Costs = (850 CCF)(\$0.60/CCF)
 Annual Fuel Costs = \$510/yr

Alternative No. 1

Annual Fuel Costs = (283 CCF)(\$0.60/CCF)
 Annual Fuel Costs = \$169/yr

Alternative No. 2

Annual Fuel Costs = (286 CCF)(\$0.60/CCF)
 Annual Fuel Costs = \$172/yr

Alternative No. 3

Annual Fuel Costs = (197 CCF)(\$0.60/CCF)
 Annual Fuel Costs = \$118/yr

AFS

Alternative No. 1

Annual Fuel Savings = $AFC_C - AFC_A$

Annual Fuel Savings = (\$510/yr) - (\$169/yr)
 Annual Fuel Savings = \$341/yr

Alternative No. 2

Annual Fuel Savings = (\$510/yr) - (\$172/yr)
 Annual Fuel Savings = \$338/yr

Alternative No. 3

Annual Fuel Savings = (\$510/yr) - (\$118/yr)
 Annual Fuel Savings = \$392/yr

ACS

The annual cost savings are equal to the Annual Fuel Savings when there are no Annual Operating Costs.

SPP

Alternative No. 1

Simple Payback Period = $\frac{IC}{ACS}$ (\$/yr)

Simple Payback Period = $\frac{\$1283}{\$341/yr}$

Simple Payback Period = 3.76

Alternative No. 2

Simple Payback Period = $\frac{\$1148}{\$338/yr}$

Simple Payback Period = 3.39

Alternative No. 3

Simple Payback Period = $\frac{\$1544}{\$392/yr}$

Simple Payback Period = 3.94

The results of the three alternatives are very similar. The SPP range from 3.39 to 3.94 years and are all within the defined payback period. However, as discussed earlier, only one alternative can be selected. In this situation where the payback periods are very similar, alternative No. 3 would be the best choice based on its higher Annual Fuel Savings because it would result in greater savings than Alt. No. 1 and 2 over the life of the building.

8.4 Potential Capital ECOs

The previous study concluded that there were several capital ECO items that could be implemented to improve the energy efficiency of IDOH buildings [1]. The capital ECO items that were determined to be cost effective are presented in Tables 8.1 to 8.5. This should give the energy auditor a feeling for the types of items that will work. However, because the items presented in these tables worked for their respective building does not mean that they will work for the next building. This is due to the different operating conditions that the buildings operate under. Therefore, each item should be evaluated for each building independently of previous results.

The alternatives listed in Tables 8.1 to 8.5 are presented to give the energy auditor a listing of potential capital ECOs that may apply to the buildings currently being

audited. This list is not inclusive however and the energy auditor should use his imagination and judgement to come up with additional items that might provide potential cost effective energy consumption reduction.

Table 8.1 Building Type I Alternatives

ALTERNATIVE SELECTED	ESTIMATED INITIAL COST	ESTIMATED ANNUAL ENERGY SAVINGS
1.Natural Gas Furnace (a)	\$1900.00	\$681.00
2.Install Ceiling Fans	278.00	110.00
3.Energy Efficient Lamps	114.00	111.00
4.Install Timer on Security Lights	100.00	111.00
TOTALS	\$2392.00	\$1013.00

(a) Natural gas will not be available at all locations.

Table 8.2 Building Type II Alternatives

ALTERNATIVE SELECTED	ESTIMATED INITIAL COST	ESTIMATED ANNUAL ENERGY SAVINGS
1.Install New Ceiling	\$3240.00	\$812.00
2.Wall Insulation	2068.00	305.00
3.Install Ceiling Fans	278.00	137.00
4.New Overhead Doors	2854.00	725.00
5.New Lighting	1270.00	(a)(250.00)
TOTALS	\$9710.00	\$1609.00

Table 8.3 Building Type III Alternatives

ALTERNATIVE SELECTED	ESTIMATED INITIAL COST	ESTIMATED ANNUAL ENERGY SAVINGS
1.Reinsulate	\$7150.00	\$980.00
2.New Overhead Door	1430.00	280.00
3.Energy Efficient Lamps	728.00	242.00
4.Install Timer on Security Lights	200.00	256.00
5.Install Ceiling Fans	525.00	166.00
TOTALS	\$10,033.00	\$1924.00

Table 8.4 Building Type IV Alternatives

ALTERNATIVE SELECTED	ESTIMATED INITIAL COST	ESTIMATED ANNUAL ENERGY SAVINGS
1. Insulate Ceiling	\$7250.00	1637.00
2. Energy Efficient Lamps	156.00	49.00
3. Install Ceiling Fans	370.00	379.00
TOTALS	\$7776.00	\$2065.00

Table 8.5 Building Type V Alternatives

ALTERNATIVE SELECTED	ESTIMATED INITIAL COST	ESTIMATED ANNUAL ENERGY SAVINGS
1. Insulation	\$11,570.00	\$2113.00
2. Install Ceiling Fans	370.00	120.00
3. Remove Windows	2849.00	291.00
4. New Overhead Doors	4400.00	1042.00
TOTALS	\$19,189.00	\$3566.00

CHAPTER 9 SUMMARY AND RECOMMENDATIONS

9.1 Introduction

The purpose of this study was to develop an energy audit manual for the Indiana Department of Highways for use in completing in-house audits of their existing buildings. The key objective in putting the manual together was to prepare a series of step by step procedures that would allow an individual to effectively audit an IDOH facility. To accomplish this objective, the manual was divided into key chapters with step by step procedures for completing separate energy evaluations. Several examples were included to illustrate the procedures and help clarify the material presented.

The methodology used in this manual is based on procedures used in the previous energy study by G. Smith [1]. However, users of this manual should be aware that there are some variations in calculation procedures between the initial study and this manual. These changes are few but were necessary to help simplify the calculation procedures. An example of a change between the first study and the manual

is estimating heat losses through a roof with an attic. The first study estimates an attic temperature to use as the outside air temperature. The manual ignores the attic temperature and uses the outside air temperature. By ignoring the attic temperature, the heat loss calculation is simplified and the results that are achieved provide a sufficient answer. In conclusion, the user should not be alarmed by differences in procedures between the original study and the manual. The calculation procedures outlined in the manual should take precedence over the original study. The changes are intended to simplify the procedures without sacrificing results.

Users of this manual are encouraged to read the first study. This study will give the user good background information into the energy audit process. Along with reading the first study, users are strongly encouraged to read the reference material cited in the manual. This will provide valuable background information for understanding the material presented in the manual.

Several good recommendations were outlined in the first study. The most important one being the formation of an energy management program. This manual was developed to enable the energy management team to perform the energy audit function of the program. Implementing the energy management program along with the other recommendations is a

decision that must be made by IDOH personnel. The researcher feels that the development of an energy management team is an important step towards implementing the energy audit manual. The recommendations that are outlined in the remainder of this chapter deal with using the manual.

9.2 Energy Audit Manual Recommendations

Implementing the manual will require a commitment of resources by IDOH. The researcher strived to write the manual in a fashion that would require minimal instructions for its use. However, completing an energy audit is not a simple process and to present the material in a form that would allow a non-engineer to complete an audit is not without problems. Therefore, training of personnel who are to use the manual is a must. The amount of training required will depend on the individual(s) background and knowledge of building energy systems. It is suggested that individual(s) selected to use the manual review the material and with their feedback determine the level of training required. There are several options open for the type and level of training that can be provided.

1. A series of short courses could be prepared in the use and understanding of the manual. These courses could be held at the Research and Training Center in West Lafayette, Indiana.

2. Another possibility is to have individuals take courses at Purdue. This will depend on the individuals access to the campus and work schedule. However, if it were possible for an individual(s) to take CE 525 and 625, it would allow them to understand the material presented in the manual and develop some of the necessary skills required for completing the analysis sections of the manual.
3. The selection of individuals who are interested in performing energy audits and are willing to read additional material in this area will reduce the amount of necessary outside training. The collection of data for completing the necessary calculations is straight forward. However, when the necessary calculations and analyses must be completed, the user must have a good understanding of the material presented in the manual. An individual who is interested in this area can read the reference material and gain much of the necessary background knowledge.

The amount of manpower and resources committed to training individuals in using the manual is again a decision to be made by the IDOH. There are other options available that will not require extensive training in the use of the manual.

1. Consulting firms can be utilized for the analysis sections of the manual. Once the BIF is properly filled out, it may be possible to hire outside consulting firms to do the proper calculations and analysis for determining energy conservation opportunities. However, this option will require consultant's fees to be considered in the economic evaluation of the energy conservation opportunities.
2. Computerizing the manual is another good possibility and is a recommendation for continued study. Again, individuals would be required to fill out the BIF to collect the necessary data to be used by the computer for completing the analysis. This option will not eliminate the necessary judgement and creativity that is required to come up with possible ECOs when auditing a building.
3. The final recommendation for implementing the manual is to remember that the contents presented within are not conclusive and can be improved through critical use. Users of the manual are encouraged to document problems they have in using the manual and write down suggestions for improving the contents within the manual.

9.3 Recommendations for Continued Study

Additional research and input from future manual users is needed to develop the proposed energy audit manual into a more complete system. The following recommendations are proposed for continued study towards solving the energy conservation problem.

1. The feasibility of computerizing the evaluation sections, chapters 5 through 8, of the manual should be investigated. An interactive computer program could possibly be developed for these sections. Because of the types of buildings being evaluated in this study, the interactive program would not require the sophistication of the United States Department of Energy's DOE-2 computer program or of the United States Army Construction Engineering Research Laboratory's Building Loads Analysis and System Thermodynamics (BLAST) computer program.
2. This manual is limited to the evaluation of the physical building components and the lighting system. There are cost effective energy conservation opportunities that exist in a building's mechanical and electrical systems. This is an area that should be researched and added to the manual. Included within the analysis of mechanical and electrical systems, consideration should

be given to the impact special equipment has on ventilation requirements.

3. The final area of continued research should deal with the evaluation of the methodology presented in the manual. Implementing energy conservation opportunities should occur only when they are cost effective and can pay for their implementation through utility savings. To date the energy conservation opportunities that have been selected were based on the calculation procedures presented in the manual. Therefore, the next logical step is to evaluate the buildings that have been retrofitted to determine if there has been an energy savings and how close the calculated savings match the actual. The calculation of energy utilization indexes (EUIs), as presented in Chapter 7, can be used for determining a building's overall energy consumption. By calculating EUIs for the retrofitted buildings a determination of actual energy reduction can be made. This information can then be utilized to improve the manual and to help in deciding the level of manpower and resources to commit towards solving the problem.

REFERENCES

REFERENCES

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APPENDICES

APPENDIX A

Energy Audit Forms

FORM 3.1 BUILDING INFORMATION FORM (BIF)

I. General Description

A) General:

Name of Building _____

Address _____

City _____ Telephone Number _____

District _____ Sub-District _____

Contact Person _____ Position _____

Building use: _____

B) Building Type:

Description _____

Year of Construction _____

Year(s) and Description of Modification(s) _____

C) Operating Schedule:

	Days per wk	Time from	to	Hours	Operating Temperature SUM. WIN.	No. of Occupants
DAY	_____	_____	-_____	_____	_____	_____
Evening	_____	_____	-_____	_____	_____	_____
Weekend	_____	_____	-_____	_____	_____	_____
Other	_____	_____	-_____	_____	_____	_____

II. Building Characteristics

A) Photographs of Building:

_____ Elevation

_____ Elevation

_____ Elevation

_____ Elevation

B) Building Floor Plan:**1) Floor _____**

2) Floor _____

C) Floors:

1) Location _____

a) Floor Construction

Description

Cross Section

b) Floor Dimensions

Length_____ Width_____

2) Location _____

a) Floor Construction

Description

Cross Section

b) Floor Dimensions

Length_____ Width_____

D) Walls:

1) Location _____

a) Wall Construction

Description

Cross Section

Elevation

b) Wall Construction Description and Dimensions

Construction _____ Length _____ Height _____

Construction _____ Length _____ Height _____

Construction _____ Length _____ Height _____

c) Window Construction

Single Glazed _____ sq. ft.

Double Glazed _____ sq. ft.
(space) _____ inches)

Insulating Glazed _____ sq. ft.
(space) _____ inches)

Storm Windows _____ sq. ft.

Other (specify) _____ sq. ft.

Shading (specify) _____ sq. ft.

Window Frame Type _____

Frame Width _____ inches

d) Door Construction

Description	No.	Usage (Per/hr)	Thickness (inches)	Height (ft-in)	Width (ft)	Area (sf)

e) Infiltration

Cracks through walls None ____ Few ____ Many ____

Loose-fitting windows _____

Loose-fitting doors _____

Loose-fitting air conditioners _____

Ventilation exhaust ducts without dampers _____

Others observed (describe) _____

2) Location _____

a) Wall Construction

Description

Cross Section

Elevation

b) Wall Construction Description and Dimensions

Construction _____ Length _____ Height _____

Construction _____ Length _____ Height _____

Construction _____ Length _____ Height _____

3) Location _____

a) Wall Construction

Description

Cross Section

Elevation

b) Wall Construction Description and Dimensions

Construction _____ Length _____ Height _____

Construction _____ Length _____ Height _____

Construction _____ Length _____ Height _____

c) Window Construction

Single Glazed _____ sq. ft.

Double Glazed _____ sq. ft.
(space) _____ inches

Insulating Glazed _____ sq. ft.
(space) _____ inches

Storm Windows _____ sq. ft.

Other (specify) _____ sq. ft.

Shading (specify) _____ sq. ft.

Window Frame Type _____

Frame Width _____ inches

d) Door Construction

Description	No.	Usage (Per/hr)	Thickness (inches)	Height (ft-in)	Width (ft)	Area (sf)

e) Infiltration

Cracks through walls None ____ Few ____ Many ____

Loose-fitting windows _____

Loose-fitting doors _____

Loose-fitting air conditioners _____

Ventilation exhaust ducts without dampers _____

Others observed (describe) _____

4) Location _____

a) Wall Construction

Description

Cross Section

Elevation

b) Wall Construction Description and Dimensions

Construction _____ Length _____ Height _____

Construction _____ Length _____ Height _____

Construction _____ Length _____ Height _____

E) Roof:

1) Location _____

a) Roof Construction

Description

Cross Section

b) Roof Dimensions

Width _____ Length _____ Pitch _____

c) Roof Color and Condition

Color light _____ dark _____

Condition good _____ fair _____ poor _____
 age _____

d) Sky Lights

Description

Cross Section

e) Skylight Area

No. _____ * Length _____ * Width _____ = _____ sq. ft.

No. _____ * Length _____ * Width _____ = _____ sq. ft.

2) Location _____

a) Roof Construction

Description

Cross Section

b) Roof Dimensions

Width _____ Length _____

c) Roof Color and Condition

Color light _____ dark _____

Condition good _____ fair _____ poor _____

d) Sky Lights

Description

Cross Section

e) Sky Light Area

No. _____ * Length _____ * Width _____ = _____ sq. ft.

No. _____ * Length _____ * Width _____ = _____ sq. ft.

III. Major Energy Using Systems

A) Fill in the appropriate numbers for items 1 thru 5 using the numbered codes listed on the next page:

	Fuel Type (A)	Mechanical Equipment (B)	Terminal Unit (C)	Thermostat Setting- F	
				Sum.	Win.
1. Space Heating	_____	_____	_____	_____	_____
2. Space Cooling	_____	_____	_____	_____	_____
3. Hot Water	_____	_____	_____	_____	_____
4. Kitchen	_____	_____	_____	_____	_____
5. Kitchen equipment description	_____				

A. Fuel Type:

01 Coal	06 Propane
02 Electricity	07 Purchased Steam
03 No. 2 Fuel Oil	08 Wood
04 No. 6 Fuel Oil	09 Other (specify) _____
05 Natural Gas	

B. Mechanical Equipment:

Heating System	Cooling System	Hot Water System
10 Low pressure steam boiler	17 Absorption	24 Hot water heater
11 High pressure steam boiler	18 Centrifugal	25 Boiler heat exchanger
12 Hot water boiler	19 Reciprocating	26 Booster/reheat
13 Forced air furnace	20 Window/wall unit	27 Solar assisted
14 Resistance	21 Heat pump	28 Other _____
15 Heat pump	22 Other _____	(specify)
16 Other _____	(specify)	
(specify)		

C. Terminal Units

29 Radiator	33 Dual duct	37 Self-contained
30 Fan coil/radiator	34 Variable air vol.	38 Circulating
31 Single zone	35 Induction	39 Non-circulating
32 Multi-zone	36 Terminal unit	40 Other _____
		(specify)

D. Efficiency analysis

Unit Description _____

Nameplate	Nameplate	
Output(BTU/hr) _____	Input(BTU/hr) _____	= Efficiency _____%

Unit Description _____

Nameplate	Nameplate	
Output(BTU/hr) _____	Input(BTU/hr) _____	= Efficiency _____%

Unit Description _____

Nameplate	Nameplate	
Output(BTU/hr) _____	Input(BTU/hr) _____	= Efficiency _____%

B) Lighting Interior:

[illegible]

C) Lighting Exterior:

1) Building Perimeter

Location	Type	Total Watts	Method of control	Usage (hrs/wk)
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____

2) Parking Area

Location	Type	Total Watts	Method of control	Usage (hrs/wk)
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____

IV. Climatic Data

Outside Temperature (winter) _____

Average Annual Heating Degree Days _____

Average Annual Cooling Degree Days _____

Main Wind Direction and Velocity _____

V. Description of Energy Management Activities

Energy Management Team Formed Yes _____ NO _____

Energy Management Coordinator Designated Yes _____ NO _____

Energy Audit Completed _____ Started _____ None _____

Detailed Study by Architect or Engineer
Completed _____ Started _____ None _____

Energy Management Measures Implemented and Dates

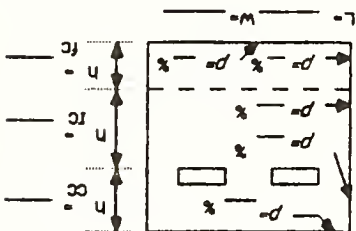
VI. Field Inspection Notes

FORM 6.1 Zonal Cavity Calculation Form

GENERAL INFORMATION

Building and Room Identification _____
 Average maintained illumination for design _____ fc
 Lamp Data _____
 Type and color: _____
 Number per luminaire: _____
 Total lumens per luminaire: _____
 Manufacturer: _____
 Catalog number: _____

SELECTION OF COEFFICIENT OF UTILIZATION



STEP 1: Fill in sketch at right

STEP 2: Determine Cavity Ratios by formulas.

Room Cavity Ratio, RCR = _____
 Ceiling Cavity Ratio, CCR = _____
 Floor Cavity Ratio, FCR = _____

SELECTION OF LIGHT LOSS FACTORS

STEP 3: Obtain effective ceiling cavity reflectance (pcc) from Table 6.5.
 $p_{cc} =$ _____

STEP 4: Obtain effective floor cavity reflectance (pfc) from Table 6.5.
 $p_{fc} =$ _____

STEP 5: Obtain coefficient of utilization (CU) from Table 6.6.
 $CU =$ _____

STEP 6: Determine Light Loss Factors

Unrecoverable luminaire ambient temperature _____
 Voltage to luminaire _____
 Ballast factor _____
 Luminaire surface depreciation _____
 Total light loss factor, LLF (product of individual factors above) _____

Recoverable room surface dirt depreciation _____
 Lamp lumen depreciation _____
 Lamp burnout factor _____
 Luminaire dirt depreciation LDD _____

CALCULATIONS

STEP 7: Complete Calculations as follows:

(Average maintained illumination level)

Number of luminaires = $\frac{(\text{footcandles}) \times (\text{Area in square feet})}{(\text{lumens per luminaire}) \times (CU) \times (LLF)}$ (Eq. 6.4)

Number of luminaires = _____

Footcandles = $\frac{(\text{Number of luminaires}) \times (\text{lumens per luminaire}) \times (CU) \times (LLF)}{(\text{Room Area, } L \times W, \text{ in sq ft})}$ (Eq. 6.5)

Footcandles = _____

Calculated by: _____
 Date: _____

FORM 7.1 ENERGY MANAGEMENT FORM

BUILDING _____

YEAR _____

MONTH	HEATING DEGREE DAYS	COOLING DEGREE DAYS	ELECTRICITY				OIL				NATURAL GAS				COAL -- WOOD --		PURCHASED STEAM -- OTHER --				TOTAL ENERGY COST
			QUANTITY KWH	COST (DOLLARS)		QUANTITY GALLONS	COST (DOLLARS)		QUANTITY MCF	COST (DOLLARS)		QUANTITY MCF	COST (DOLLARS)		QUANTITY UNIT	COST (DOLLARS)		TOTAL \$	\$/UNIT \$/MMBTU		
				TOTAL \$	\$/KWH		TOTAL \$	\$/GAL.		TOTAL \$	\$/MCF		TOTAL \$	\$/MCF		TOTAL \$	\$/UNIT				
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20		
JAN.																					
FEB.																					
MAR.																					
APR.																					
MAY																					
JUN.																					
JUL																					
AUG.																					
SEP.																					
OCT.																					
NOV.																					
DEC.																					
ANNUAL TOTALS			A				B				C				0						
ANNUAL AVERAGES																					

BUILDING DATA

GROSS CONDITIONED AREA (SQ FT) _____

GEN. NOTES: _____

ANNUAL ENERGY CONSUMPTION IN BTU

QUANTITY

ELECTRICITY

OIL

NATURAL GAS

OTHER FUEL

KWH

GALLONS

MCF

K

K

K

K

K

K

K

K

CONVERSION FAC.

KWH

GALLONS

MCF

K

K

K

K

K

K

K

K

K

K

K

K

K

ENERGY UTILIZATION INDEX

EUI =

TOTAL ENERGY CONSUMPTION BTU/YR

GROSS CONDITIONED AREA (SQ FT)

EUI =

TOTAL ENERGY CONSUMPTION BTU/YR

GROSS CONDITIONED AREA (SQ FT)

EUI =

TOTAL ENERGY CONSUMPTION BTU/YR

GROSS CONDITIONED AREA (SQ FT)

EUI =

TOTAL ENERGY CONSUMPTION BTU/YR

GROSS CONDITIONED AREA (SQ FT)

EUI =

TOTAL ENERGY CONSUMPTION BTU/YR

GROSS CONDITIONED AREA (SQ FT)

EUI =

TOTAL ENERGY CONSUMPTION BTU/YR

FORM 8.1 POTENTIAL ENERGY CONSERVATION OPPORTUNITIES
SIMPLE PAYBACK ANALYSIS FORM

Item _____ Date _____

STEP 1

Description _____

Input Data	STEP 2	Label	Item	Current System	Alternative No. 1	Alternative No. 2	Alternative No. 3
		IC	Initial Costs (\$)				
		FC	Fuel consumption (units/yr)				
		FP	Projected Average Fuel Price (\$/Unit)				
		AOC	Annual Operating Costs (\$/yr)				
Calculations	STEP 3	AFC	Annual Fuel Costs = $FC \times FP$ (\$/yr)				
		AFS	Annual Fuel Savings = $AFC_C - AFC_A$ (\$/yr)				
		AC	Annual Costs = $AFC + AOC$				
		ACS	Annual Cost Saving = $AC_C - AC_A$ (\$/yr)				
		SPP	Simple Payback Period = IC / ACS (\$/yr)				

APPENDIX B

Noncapital Energy Conservation
Opportunity Checklist

NONCAPITAL ECO CHECKLIST
FOR
MAINTENANCE AND OPERATIONAL CHANGES

The following checklist is to be used during the building site visit. Items that apply to the building being audited should be checked off and the proper action taken.

A. General Building

1. ☐ Reduce the use of heating and cooling systems in spaces which are used infrequently or only for short periods of time.
2. ☐ Windows or outside doors left open during the heating or cooling seasons represent an energy loss if the heaters or air conditioners are running. Make sure they are shut.
3. ☐ Involve building staff with energy conservation measures so that each individual has responsibility.
4. ☐ Change the spring, fall and winter day-night timeclock settings to operate heating, ventilation, and cooling equipment fewer hours on the day cycle.
5. ☐ Disconnect all refrigerated water fountains if acceptable to occupants.

6. ___ Be certain that all operable windows have sealing gaskets and cam latches that are in proper working order.
7. ___ Close off unused areas and rooms. Where possible, be certain that blinds or other shading devices are drawn, registers closed, etc.
8. ___ Seal ducts and access doors in equipment rooms to minimize bypassing of hot and cold air.
9. ___ Schedule operating, maintenance and cleaning to overlap more with normal working hours or when daylight is available and sufficient for the task.
10. ___ Lower the thermostats during the heating season and raise them during the cooling season. You can save about 8% of your heating fuel bill by lowering the thermostats a mere five degrees.
11. ___ Set back the heating season thermostats 10deg F during the night.
12. ___ Lower the domestic hot water to 110 deg F.
13. ___ Turn off the cooling system during the night. Use ventilation air to cool the building.

B. SPACE HEATING - GENERAL

1. ___ Set all thermostats at 68deg F or less for winter space heating.
2. ___ Surfaces of radiators, convectors, baseboards, and finned-tube heaters must be kept clean for efficient operation.
3. ___ If you use hot water for heating, reduce the space heating hot water temperature to a level that will just satisfy heating needs.
4. ___ Do not heat storage rooms unless it is necessary for protection of stored contents and water lines.
5. ___ If you have infrared heaters, check to see if the reflectors are beamed in the right direction, and the surface is clean.

COVER DESIGN BY ALDO GIORGINI